US ARMY TEST & EVALUATION COMMAND

LEVEL II

AD A072434

Project No. 9 CO 150 000 09S
Report No. 790401

MATERIEL TESTING IN THE TROPICS

Sixth Edition
April 1979

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U. S. ARMY TROPIC TEST CENTER
APO MIAMI 34004

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(Formerly Tropic Environmental Effects)
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Sixth Edition, April 1979

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FOREWORD

This Sixth Edition of Materiel Testing in the Tropics was prepared by the technical staff of the US Army Tropic Test Center. It is an update of available information relevant to materiel testing in the humid tropics. The report includes a synthesis of materiel tests and methodology studies conducted by USATTC in the Panama Canal Zone, supplemented by pertinent information available in the literature. Its purpose is to acquaint materiel developers and evaluators engaged in military RDTE activities with the humid tropic environment and its effects on materiel performance.

Materiel testing has been conducted in the Canal Zone since World War II, and this Center is continuously refining knowledge of environmental effects on the durability and performance of all types of materiel. Future test results will contribute to broadening that foundation. Information tailored specifically to a particular test, location or materiel can be obtained from the published reports or from this Center.

It is believed that this report provides a significant step toward meeting the short-term and long-term goals of providing information that will assist the RDTE community to reach a better understanding of the humid tropics and its effects on man and materiel.

WENDELL L. PRINCE
Colonel, Armor
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: TECOM Project No. 9 CO 150 000 099	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Materiel Testing in the Tropics		5. TYPE OF REPORT & PERIOD COVERED: Sixth Edition, -April 1979
		6. PERFORMING ORG. REPORT NUMBER: USATTC ~~Report No.~~ 790401
7. AUTHOR(s): US Army Tropic Test Center Staff		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Tropic Test Center, ATTN: STETC-TD, APO Miami 34004		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Test and Evaluation Command, Aberdeen Proving Ground, MD 21005		12. REPORT DATE: April 1979
		13. NUMBER OF PAGES: 269
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Accelerated tests	Elastomers
Armed conflict in tropical regions	Electronic materiel
Auditory localization	Herbicides
Canal Zone analogs	Human factors engineering in tropic tests
Computerized site selection methods	Human performance (cont)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Practically every materiel development effort and subsequent procurement of materiel for Army use must undergo developmental testing to ensure that specified performance criteria are met in a variety of climatic categories. It is thus highly desirable to have ready access to a document that is an update of available information in terms of appropriate environmental descriptions, and their known and perceived effects on man and materiel as an aid in planning and executing effective environmental tests. The objective (cont)

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19. (cont)

Jungle load-carrying
Laboratory versus field tests
Metals
Methodology
Munitions and explosives
Optics and ceramics
Panama Canal Zone
Plastics
Protective coatings
Radio frequency energy propagation
Reliability and maintainability
Seismic propagation
Sensor tests
Sound propagation
Test methodology
Textiles
Tropic Test Center
Tropical animals

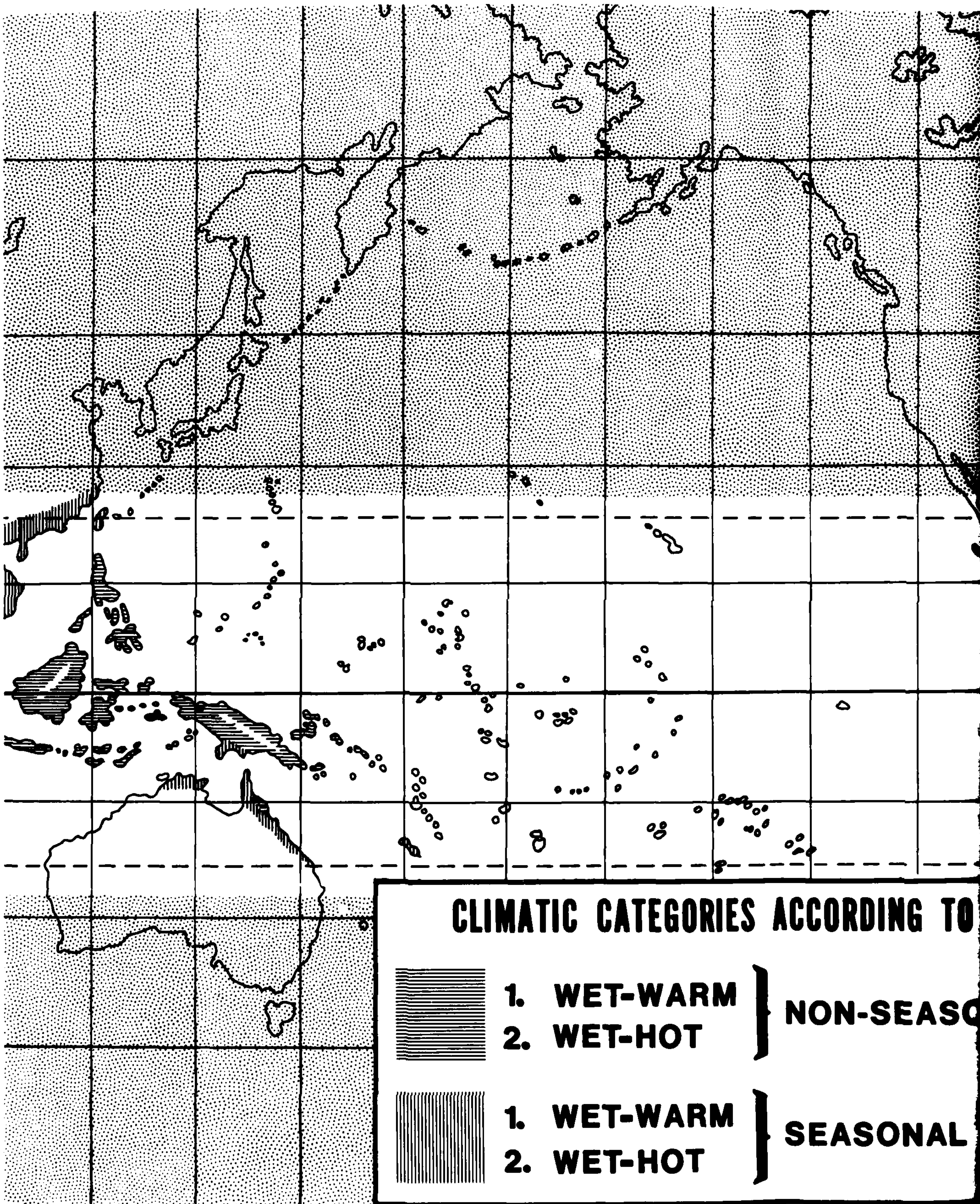
20. (cont)

Cont

of Materiel Testing in the Tropics is to meet such needs by periodically updating information pertinent to testing materiel in the humid tropics.

The report is a compendium of the US Army's experiences and available literature in testing materiel in the humid tropics, and special investigations conducted by USATTC to better understand the effects of the environment on the performance of man and materiel. Topics include the need for tropic testing, an environmental description of the Panama Canal Zone, degrading environmental factors, tropic degradation of selected materials and materiel, materiel reliability and maintainability, and effects of the jungle on man and materiel.

This document should provide valuable information for those who design, evaluate or use equipment in the humid tropics.



CLIMATIC CATEGORIES ACCORDING TO
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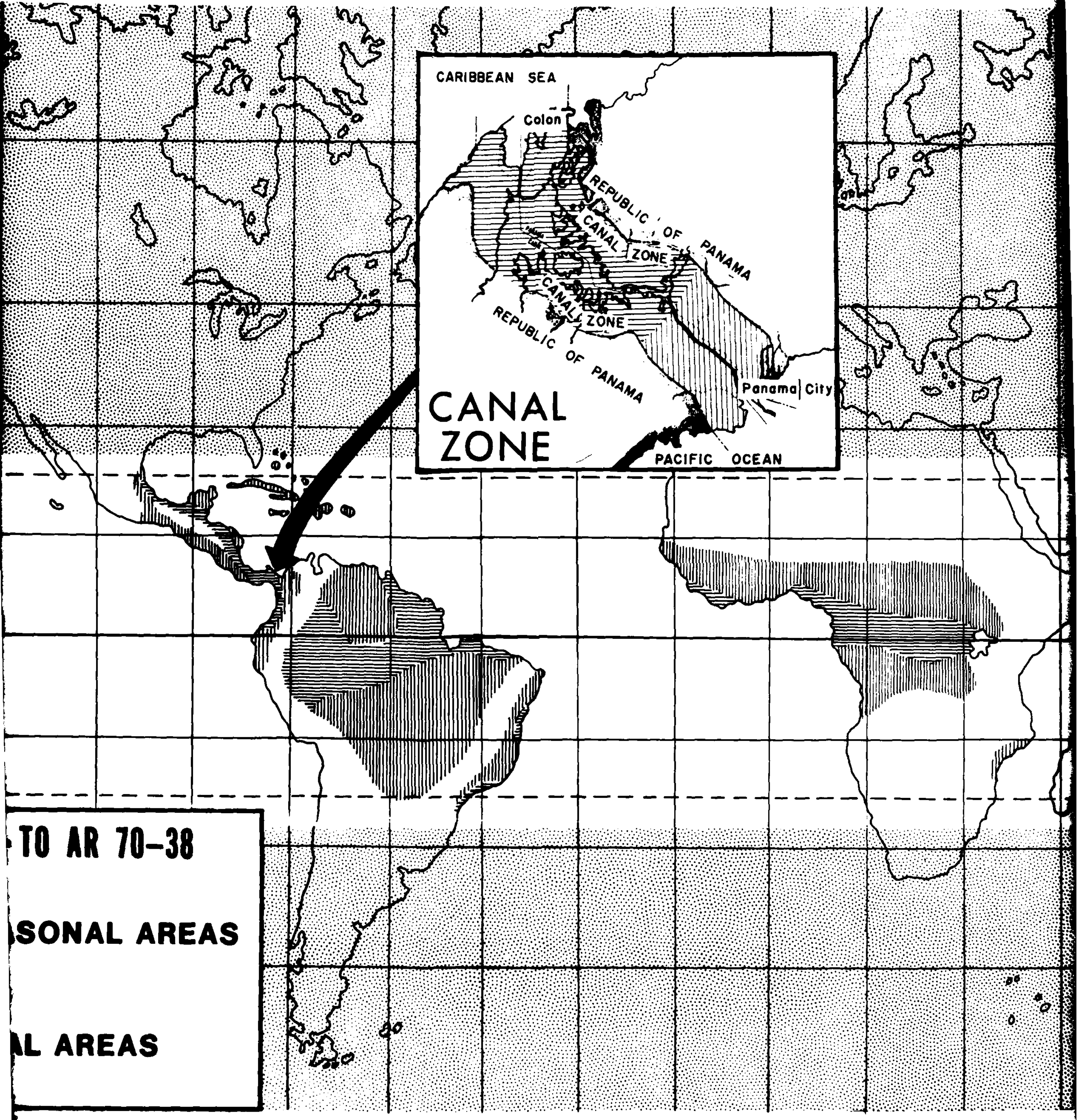
2. WET-HOT
NON-SEASO
1. WET-WARM
2. WET-HOT
SEASONAL



CARIBBEAN SEA
Colon
REPUBLIC OF PANAMA
CANAL ZONE
CANAL ZONE
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Panama City
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PACIFIC OCEAN
TO AR 70-38
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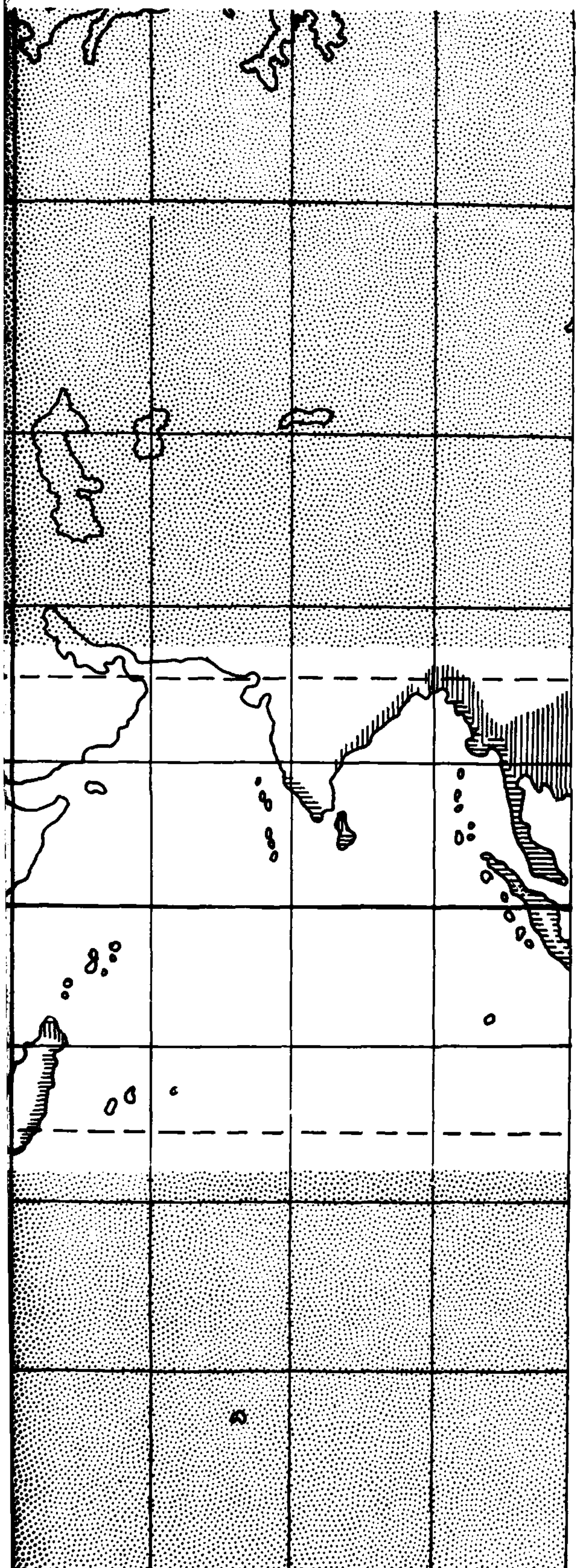

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SECTION I. BACKGROUND

A. RATIONALE FOR FIELD ENVIRONMENTAL TESTING

According to AR 70-38,* standard general purpose materiel must be designed for safe and effective use in the intermediate and wet climatic categories (Categories 1, 2, 5 and 6, table I-1). The wet climatic categories include the humid tropic regions of the world. A well designed climatic test program for Army materiel usually includes both chamber and field tests. The chamber tests play a vital role in the early stages of materiel development by providing a rapid, inexpensive means of uncovering design problems. The field tests provide verification of acceptable design under extreme, expected-use conditions.

The major world powers recognize the need for field testing of materiel in the humid tropics. In addition to the United States which maintains a center in the Panama Canal Zone, Great Britain and Australia utilize a hot, humid test facility in Northwestern Australia, and communist countries conduct extensive testing in the tropics of Hanoi, Havana and Canton regions.

B. RATIONALE FOR TESTING IN THE HUMID TROPICS

United States involvement in military operations in the humid tropics during World War II and the Vietnam conflict revealed many unexpected materiel and operational problems. The combination of warm temperatures, high rainfall and high humidities interact to produce an environment which adversely affects the performance of materiel.

A 1975 study by the Tactical Technology Center (TACTEC) of Battelle Laboratories, reported that 99 countries had been involved in either international warfare or internal violence from 1969 to 1975. The US Army Tropic Test Center (USATTC) categorized the 99 countries involved as to whether they lay totally in, partly in, or totally out of the tropics. Bar charts were made showing the frequency of involvement of the three categories of nations in international and internal conflicts. Figure I-1 shows the international conflict category which indicates a fairly even spread of conventional warfare between tropic and nontropic regions. Figure I-2 shows the internal violence category only, and dramatizes the political turbulence of the world's developing nations of Asia, Africa and Latin America. The tropics, representing approximately one-third of the world's land area and only 20 percent of the world's population, were responsible for 66 percent of the internal conflicts. If nations partly in and partly out of the tropics are added, the percentage is raised to 80 percent. Figure I-3 combines all three categories of conflicts.

* AR 70-38, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions, 5 May 1969.

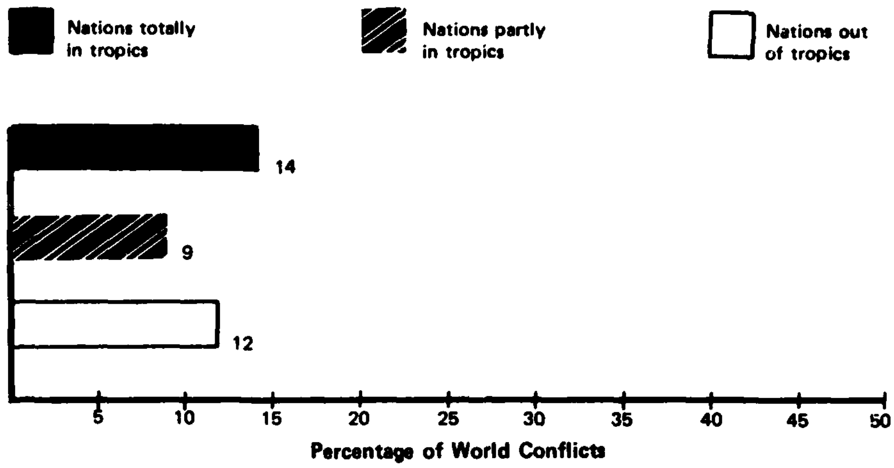


Figure I-1. International Conflicts 1960–1975 (Excludes All Internal Conflicts).

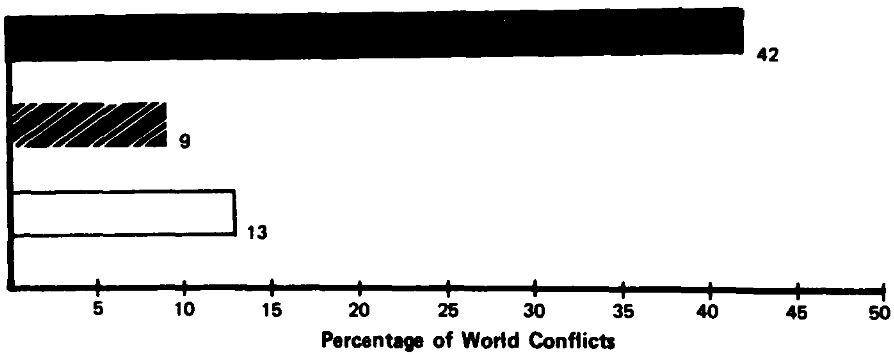


Figure I-2. Internal Conflicts of the World 1960–1975 (Includes All Internal Conflicts; Excludes International Wars).

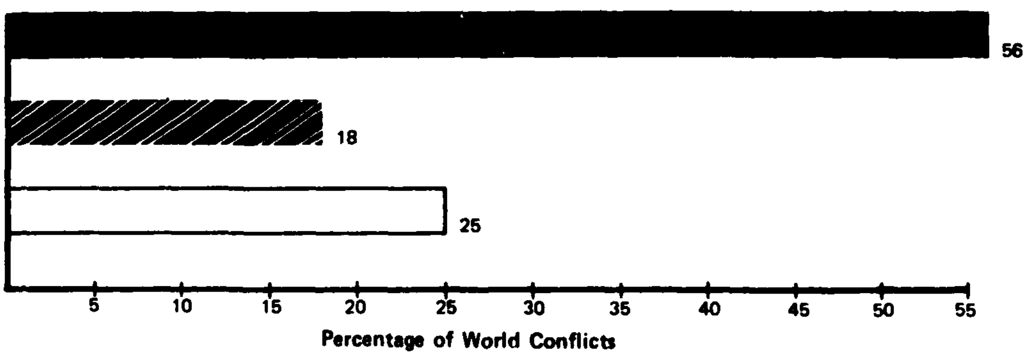


Figure I-3. World Conflicts 1960–1975 (Includes International and All Internal Conflicts).

Countries totally in the tropics accounted for 57 percent of all conflict involvements, those countries partly in the tropics accounted for 18 percent, and those outside the tropics only 25 percent.

For the world as a whole then, during the 16-year period ending in 1975, 75 percent of all conflicts have occurred in countries whose land masses were totally or partly in the tropics. There is no evidence that the trend has changed.

In a 1976 USATTC study, US Army Security Assistance Program to Tropical Countries, it was pointed out that of the approximately 150 countries and territories of the world, 79 (53 percent) have tropic climates within their borders. Of these 150 countries, the United States Army has security assistance programs with 83 of which 46 (55 percent) are tropical. Through the security assistance programs, the United States has sold billions of dollars of military materiel in tropic countries.

This study emphasized that both direct and indirect economic benefits accrue to the United States from foreign military sales. Sales of high quality materiel generate favorable relations with tropic nations--most of which have not reached their full economic potential--and represent an investment for more significant economic benefits in the future. However, whether military equipment is used by United States troops in the tropics or is sold to tropic nations or nations which operate in the tropics, there must be assurance that the equipment will function properly and last in that environment. The need for materiel suitable for use in the tropics is clear. Tropic testing contributes to filling this need.

C. RATIONALE FOR CONDUCTING TROPIC TESTING IN THE CANAL ZONE

Numerous studies have been conducted to estimate the analogy between environmental factors in the Canal Zone and those in other regions of the world. These have been summarized by USATTC (Smith, 1972). The Canal Zone environment is analogous to extensive humid tropic areas throughout the world (table I-1).

Alternate areas available to the United States for testing purposes include Puerto Rico, Hawaii, Guam and the Trust Territories. Puerto Rican lowlands exhibit lower humidity than the Canal Zone due to the trade winds that blow constantly. The only humid tropic areas are in the mountains of the El Yunque National Park which are limited in size for testing purposes. The islands of Hawaii and Maui have areas in which the rainfall exceeds that of the Canal Zone with comparable humidity patterns; however, these areas are at higher elevations and are somewhat cooler than the Canal Zone. Guam is an excellent climatic analog of the Canal Zone, but suffers as a prospective test area because of its small size, dense population, and

Table I-1. Canal Zone Analogs

Area \ Parameter	Composite Climate Conditions	Temperature	Precipitation	Humidity	Cloud** Cover	Wind** Speed	Vegetation	Terrain
Middle America*	2	3	3	3	2	3	B	B
South America without southern part	3	2-4	4	3	3	2	B	B
India and Southeast Asia	2,3	3	4	3	3	3	B	C
East Central Africa	0	1	1	0	0	0	B	B
West Central Afica	2	3	2	1	1	1	A	A
Africa between 10° and 18° south and Madagascar	2,3	2	2,3	2	2	1	B	B
Indonesia, Philippines and Borneo	4	4	4	4	3	2	C	C
Australia-north and northeast excluded	0	0	0	0	0	0	A	A
Northeast Australia	4	3	4	3	3	3	A	A
New Guinea	4	4	4	4	3	3	C	B
Pacific Islands-especially Guam	4	4	3	3	2	2	B	C
Thailand	3	3	2	2	2	2	C	C
Far East	2	2	2	3	3	1	A	B
Hawaii-Hilo and Maui only	4	3	4	3	2	2	B	B

LEGEND:

Climatic Factors

0 - Areas not analogous
1 - Limited analogy during certain seasons
2 - Limited analogy during most of year
3 - Extensive analogy during certain seasons
4 - Extensive analogy during most of year

Other Environmental Factors

Blank - Parameter not studied
A - Areas not analogous
B - Areas with limited analogy
C - Areas with extensive analogy

* Middle America comprises Central America, Mexico, West Indies, and Southeastern United States.
** Only wet months considered in study.

lack of jungle canopy caused by years of cultivation. The Trust Territory islands and atolls are so small that they could be used only for static exposure tests. The largest islands range from 30 to 190 square miles, with relatively heavy populations ranging from 10,000 to 30,000 people. Function testing, such as munitions firing, is probably not possible.

When these considerations are combined with the practical considerations of distance from the continental United States, relatively low shipping costs and availability of combat soldiers, it becomes evident that the Canal Zone is the most logical choice for the Army's environmental testing requirements.

D. MATERIEL TESTING IN THE PANAMA CANAL ZONE

The United States Government developed interest in tropic testing of materiel in the late 1930s. Testing at that time, under the auspices of the Panama Canal Company, was limited to investigations of corrosion and methods of corrosion control.

At the onset of World War II, high equipment failure rates in the South Pacific war zone were attributed to climatic conditions. The military services implemented a crash program to evaluate materiel under tropic conditions. This program led to the establishment of numerous test sites within the Canal Zone for testing equipment.

Efforts to establish a permanent tropic test facility began in the early 1950s. Surveys were made of several sites and the Canal Zone was selected as an appropriate site for the tropic test facility. Because of funding problems, these plans were laid aside until 1959 when the Army Scientific Advisory Panel recommended establishment of a tropic test facility. Based on the Panel's recommendation, the Office of the Chief of Research and Development established the US Army Research and Development Office, Panama, in 1962. The name was changed to the US Army Tropic Test Center in 1964 after the US Army Test and Evaluation Command was formed under the US Army Materiel Command, now US Army Materiel Development and Readiness Command (DARCOM).

Because of equipment failures and operational problems encountered in Southeast Asia, increasing emphasis was placed on tropic testing. The continuing need for an Army tropic proving ground for new equipment is based on the unique problems presented by the environment. Major military operational problems are as follows:

Surveillance/Detection. Dense tropic vegetation provides concealment from air-to-ground and ground-to-ground target acquisition. Optical, acoustic, seismic, and chemical detection systems are adversely affected by the camouflage of tropic forests, ravines, and gullies.

Communications. Jungle vegetation and topography combine to degrade the propagation of electromagnetic and acoustic energy. (Attenuation of radio signals propagated through the jungle was a major communication problem in Vietnam.)

Mobility. Thick jungle vegetation, steep slopes, and slippery and weak soils are serious obstacles to vehicular and foot mobility. Cross-country mobility in forested tropic areas is normally canalized, impeded, or impossible.

Degradation. The high humidity, the intense ultraviolet solar radiation, the high salinity of the coastal air, and the high level of micro- and macroorganism activity cause deterioration and frequent malfunctions of many kinds of materiel items and their component parts.

Human Capabilities. High temperature and humidity make it difficult to lose body heat by perspiration, lessening the physical ability of ground troops to move quickly, work long hours, or carry heavy loads for long distances. Deterrents to effective human performance are intensified by the physically taxing effects of the jungle, fear of the environment, and health and survival problems related to prolonged stays in the field.

Canopy Penetration. Aside from surveillance problems, the physical presence of the tropic forest influences any item that must penetrate it. From the air over the canopy, the accuracy of artillery fire and bombs, and the downward deliverability of materiel, aerosols and herbicides is greatly reduced. From the jungle floor upward through the canopy, penetration by gaseous signalling agents and cartridge-propelled flares or balloons is severely hampered by both the stagnant, slow moving air mass trapped there, and by the heavy biomass of the canopy itself.

E. CANAL ZONE ENVIRONMENT--BRIEF OVERVIEW

The Canal Zone (see frontispiece) bisects the Isthmus of Panama at approximately 9^{o} north latitude. The Canal Zone is approximately 55 miles long and 10 miles wide. Within this relatively small area, there exist marked differences among the environments of the Atlantic side, Mid-Isthmus (Gamboa Area), and the Pacific side of the Isthmus. Major differences include amount and timing of rainfall, amount of sunshine and density of vegetation. Two seasons prevail--the wet season (8 months) and the dry season (4 months).

Atlantic Side. On the Atlantic slope of the Canal Zone average annual precipitation varies between 2400 and 4000 millimeters, daily temperatures range from about 29^{o}C during the afternoon to 23^{o}C in the early morning hours and relative humidity is high, reaching 95 to 100 percent for several hours nearly every night. Relatively dense

forests are widespread throughout the area. This area is predominantly forested with broadleaf evergreen species which are intermixed with a lesser number of broadleaf deciduous species. The top of the forest canopy ranges from 25 to 40 meters.

Mid-Isthmus (Gamboa Area). Sandwiched between the two coastal regions, the hilly Gamboa Area displays a more continental character. Rains are strongly concentrated in the early afternoon. Their regular occurrence reduces the amount of solar radiation in comparison with the sunnier coastal areas. This leads to a reduction of daytime temperatures. While the coastal areas are frequently cloudy at night, the Gamboa Area typically has clear nights, and consequently the nighttime temperatures are lower than at the coasts. The vegetation is very dense.

Pacific Side. From Mid-Isthmus to the Pacific Ocean, precipitation decreases to less than 1700 millimeters per year at the seacoast. Normally less than 2.5 millimeters of rain per month falls during the driest months. Daily temperatures are higher than on the Atlantic side, reaching 33°C during the afternoons with early morning temperatures sometimes dropping below 21°C. Relative humidity is high, reaching 100 percent nearly every night except during the dry season. Moist evergreen forests found on the Pacific side have a larger percentage of deciduous trees than the Atlantic coast and Gamboa areas. Trees are less dense, do not grow as high, and the canopy is not as thick as that on the Atlantic slope. However, the undergrowth is much more dense. The top of the forest canopy ranges from 18 to 34 meters.

SECTION II. CLIMATIC CONDITIONS

A. INTRODUCTION

The climate in the Canal Zone is commonly referred to as humid tropic. This general term encompasses two climatic categories defined in Army Regulation 70-38--the wet-warm, category 1, and wet-hot, category 2. Table II-1 defines all categories, 1 through 5, in terms of ambient temperature, relative humidity, and radiation intensity.

Typical climatological data for the Canal Zone are presented in table II-2. The Canal Zone climate is characterized by nearly constant warm temperatures year round and in terms of rainfall by two distinct seasons. The dry season generally lasts from late December to mid-April. Reduced cloud cover during this period results in higher solar radiation loads. Trade winds blow constantly from the north at a much greater speed than in the wet season. The wet season generally begins in mid-April and extends through mid-December. The wet season can be divided into four phases. Phase 1 is a transitional period at the beginning of the season characterized by frequent rains with relatively high temperatures and little cloud cover. Phase 2 is well established by June and July. Rains remain frequent but daytime cloud cover increases resulting in lower temperatures. A slight reduction in rainfall and cloud cover occurs in Phase 3--August and September. Maximum rain and lowest temperatures are found in Phase 4--October and November.

Seasonal transitions vary as to time and year. However, for test planning purposes it can be assumed that dry season conditions will prevail by the first of February and wet season conditions will prevail by the first of June.

B. AMBIENT TEMPERATURE

Typical diurnal temperature profiles for Pacific and Atlantic sites in the dry and wet season are found in figures II-1 and II-2. Average mean maximum and mean minimum values are plotted on an hourly basis. Seasonal differences in average minimum and maximum temperatures are small compared with those of the temperate zone.

C. RELATIVE HUMIDITY

Typical diurnal relative humidity profiles for Pacific and Atlantic sites in dry and wet seasons are shown in figures II-3 and II-4. Average mean maxima and near minima are plotted on an hourly basis.

Table II-1. Climatic Categories 1 through 5 (AR 70-38)

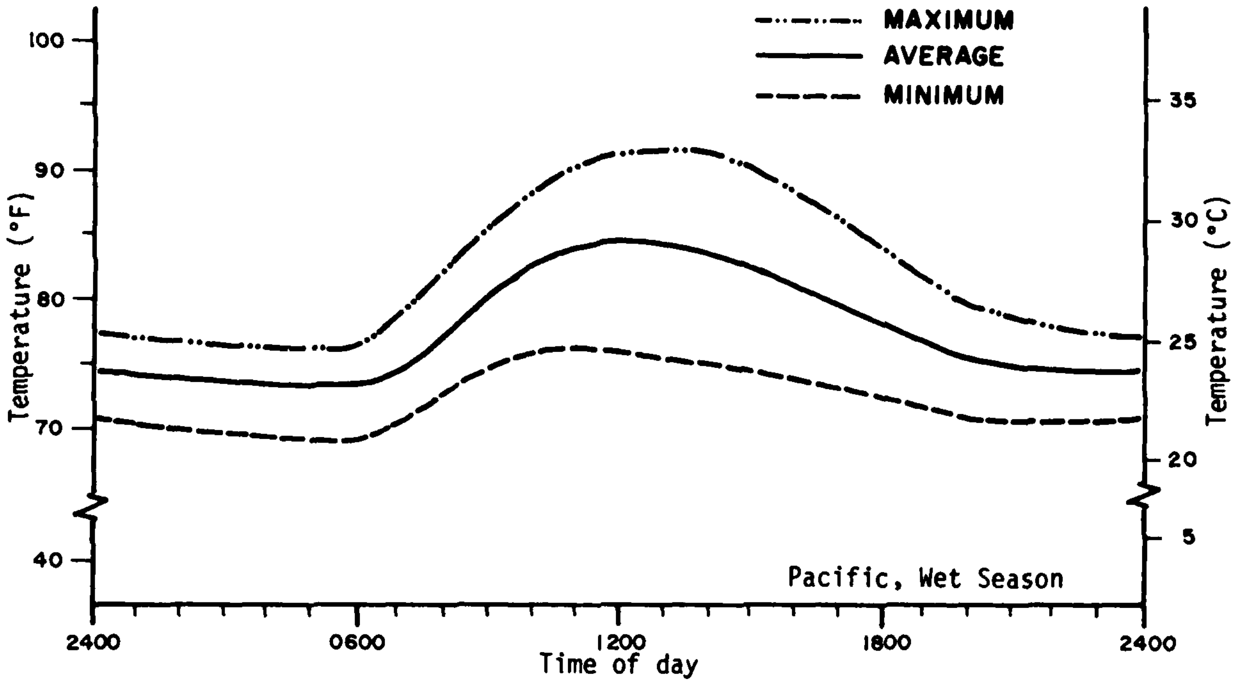
Climatic Category	OPERATIONAL CONDITIONS			STORAGE AND TRANSIT CONDITIONS	
	Ambient Air Temperature	Solar Radiation	Ambient Relative Humidity	Induced Air Temperature	Induced Relative Humidity
	°F (°C)	BTU/ft²/hr (W/m²)	%	°F (°C)	%
1 Wet-Warm	Nearly Constant 75 (24)	Negligible	95 to 100	Nearly Constant 80 (27)	95 to 100
2 Wet-Hot	78 to 95 (26-35)	0 - 360 (1135)	74 to 100	90 to 160 (32-71)	10 to 85
3 Humid-Hot Coastal Desert	85 to 100 (29-38)	0 - 360 (1135)	63 to 90	90 to 160 (32-71)	10 to 85
4 Hot-Dry	90 to 125 (32-52)	0 - 360 (1135)	5 to 20	90 to 160 (32-71)	2 to 50
5 Intermediate Hot-Dry	70 to 110 (21-43)	0 - 360 (1135)	20 to 85	70 to 145 (21-53)	5 to 50

Table II-2. Typical Weather Data, Canal Zone[a]

	Dry Season[b]			Rainy Season[c]		
	Pacific	Mid-Isthmus	Atlantic	Pacific	Mid-Isthmus	Atlantic
Ambient temperature, daytime (°C)	28 - 32	28 - 32	29 - 30	28 - 31	29 - 30	28 - 30
Ambient temperature nighttime and during heavy rain (°C)	18 - 22	18 - 21	20 - 21	24 - 26	21 - 23	24 - 26
Highest temperature ever measured (°C)	39	35	39	34	35	37
Lowest temperature ever measured (°C)	17	16	23	23	20	18
Jungle temperature, daytime (°C)	29 - 30	26 - 27	26 - 27	27 - 28	26 - 28	28 - 29
Jungle temperature, nighttime (°C)	23	23	24	24	23	24
Dew point, all day (°C)	22	21	24	24	23	24
Relative humidity, average lowest daily (%)[d]	10	13	21	21	22	23
Minimum relative humidity in jungle (%)	55	70	75	78	90	85
Duration of sunshine, daily average (hrs)	8.5	8.2	8.6	5.1	4.5	5.7
Global radiation on horizontal plane daily average ($MJ/m^2/day$)	21	18	22	14	13	14
Direct solar radiation on horizontal plane, daily average ($MJ/m^2/day$)	14	12	14	6	5	4 - 8[a]
Indirect solar radiation (sky radiation) on horizontal plane, daily average ($MJ/m^2/day$)	7	7	8	8	8	6 - 10[e]
Prevailing wind direction	N	N	NNE	NW	NNW	NW or S
Mean wind speed, noon (M/hr)	16 - 19	10	19 - 32	8 - 11	8	10 - 13
Mean wind speed, night (M/hr)	10 - 13	0	19 - 32	0 - 5	0	5 - 6
Rainfall, monthly average (mm)	13 - 25	25	38 - 50	279[f]	229 - 305	555 - 610
Rainfall, monthly maximum (mm)	180	305	406	787	940	1143
Rainfall, 24-hour maximum (mm)	122	213	229	203	432	356
Rainfall, 1-hour maximum (mm)	33	64	114	122	142	145

	Pacific	Mid-Isthmus	Atlantic
Rainfall, yearly average (mm)	2030	2670	3300
Rainfall, yearly maximum (mm)	2970	230	4650

[a] Data were derived from measurements made by the Panama Canal Company and the US Army Atmospheric Sciences Laboratory, Canal Zone Meteorological Team.
[b] Data apply to February and March--the driest months.
[c] Data apply to June through November.
[d] Maximum RH is 95--100% nightly for all areas in both seasons.
[e] Data shown are for June and July only.
[f] Data shown are for November only.



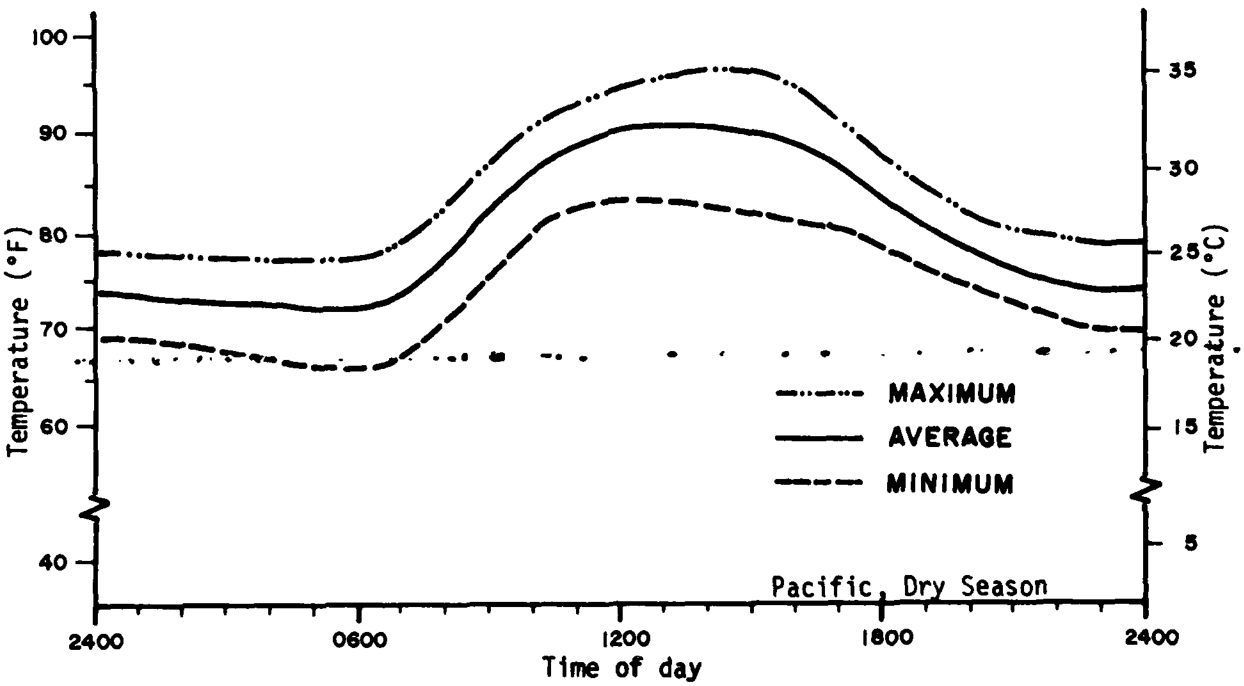


Figure II-1. Pacific Diurnal Temperature Profiles

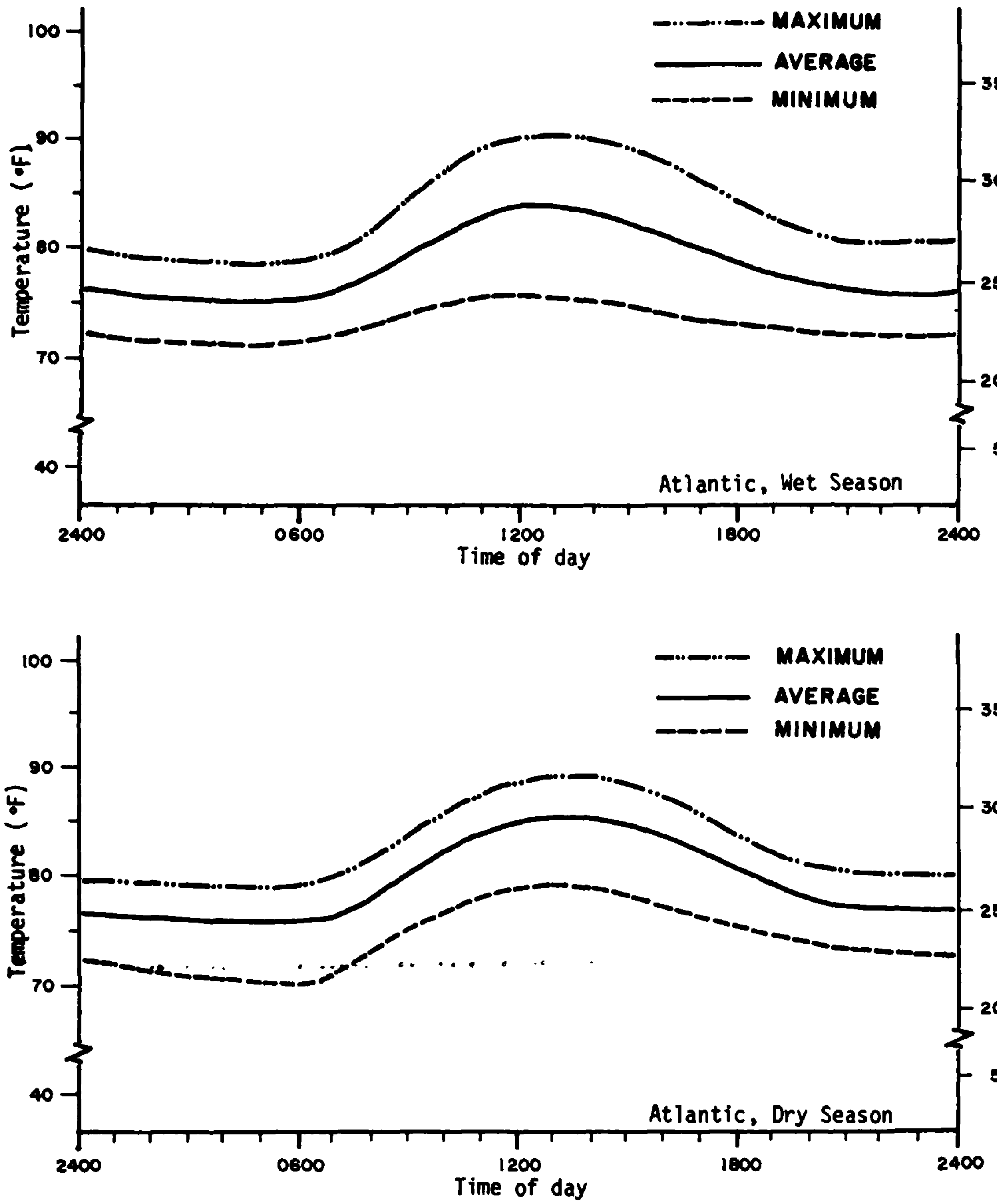


Figure II-2. Atlantic Diurnal Temperature Profiles

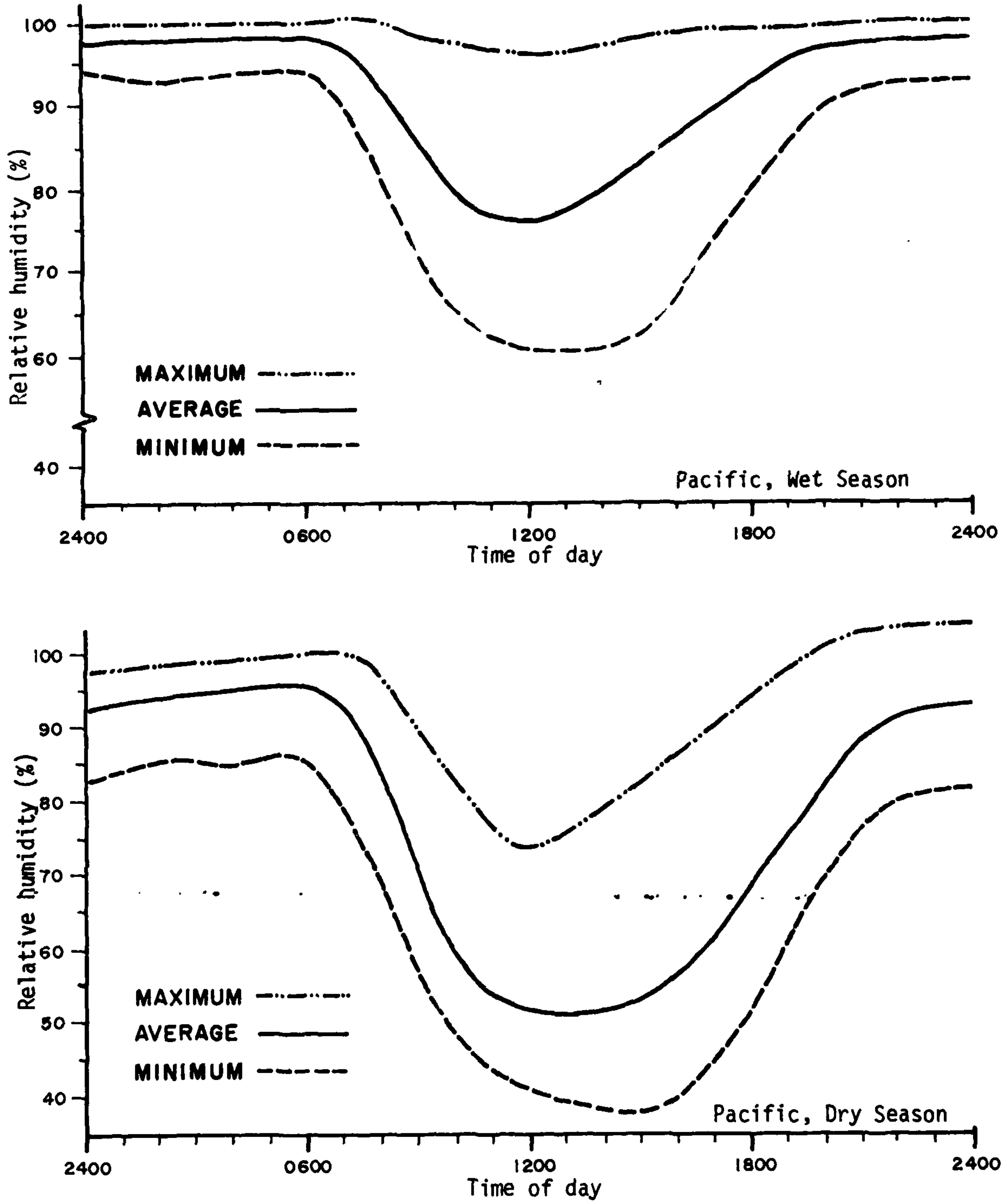


Figure II-3. Relative Humidity--Pacific Area

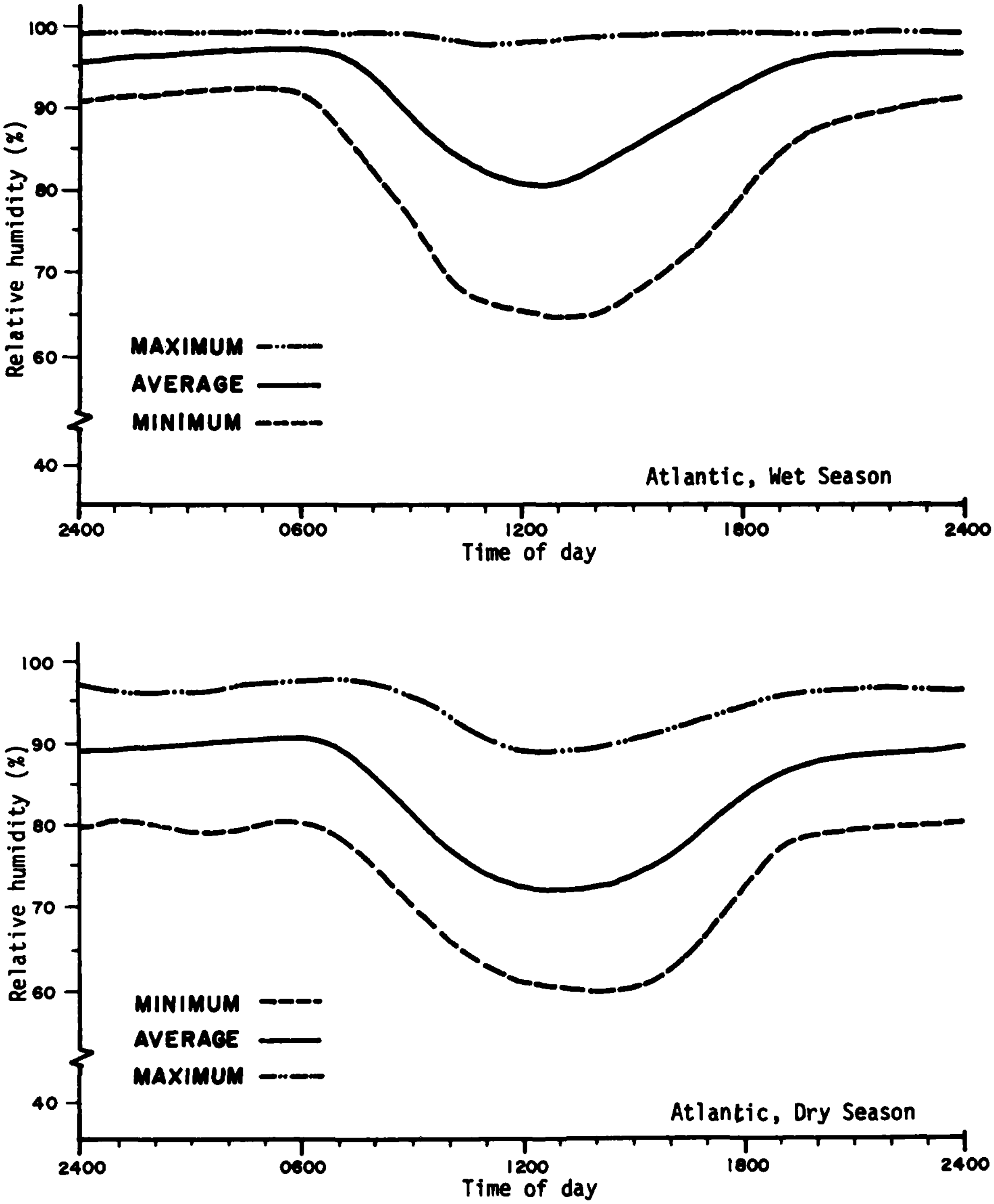


Figure II-4. Relative Humidity--Atlantic Area

All data were collected at open sites. Relative humidities under the jungle canopy would have been considerably higher.

In terms of humidity effects on materiel, two characteristics of relative humidity are important. One is the frequent occurrence of a near-saturation condition which results in condensation of water on materiel surfaces. The second is that fungi require humidities above 70 percent for active growth and reproduction, and the high humidities encountered in the Canal Zone support high levels of microbial activity.

Temperature and rainfall are easily and accurately measurable by a number of reliable techniques in any climate, but relative humidity becomes difficult to quantify as the moisture content of the air approaches saturation.

During May through June of 1976 Davis and Kalinowski (1976) conducted a methodology investigation to evaluate performance characteristics of six commercial humidity instruments--the sling psychrometer (standard), hygrothermograph, artificially aspired thermocouple, wet-bulb globe temperature sensor, the Brady Array electronic sensor, the Cambridge Dew Point System, and a USATTC in-house fabricated humidity device referred to as an aspirated thermistor. Objectives were to compare accuracy of recorded relative humidity values with respect to the sling psychrometer, determine sensor reliability with prolonged use, and determine if some sensors were better suited for specific materiel exposure modes or weather conditions. The hygrothermograph provided the most accurate, reliable performance. The more complex sensors, Brady Array and Dew Point System, exhibited the poorest performance.

D. RAINFALL

Rainfall is extremely variable in the Canal Zone both in location and time. On the average, the Atlantic side of the Canal Zone has an annual rainfall of approximately 130 inches (3302 mm). The wettest month is November averaging 22 to 24 inches (560 to 610 mm), and the driest months are February and March averaging 1 to 2 inches (25 to 50 mm). On the Pacific side of the Canal Zone, annual rainfall averages 80 inches (203 mm). The wettest months are October and November averaging 11 inches (280 mm) each, and the driest months are February and March averaging less than 1 inch (25 mm) per month. The maximum average rainfall generally occurs one-half month earlier on the Pacific side. Monthly rainfall averages for Pacific, Mid-Isthmus and Atlantic stations are shown in table II-3.

The greater rainfall on the Atlantic coast is explained by tropic wind patterns. In almost all tropic zones, easterly winds prevail with a tendency to northeast on the northern hemisphere and southeast on the southern hemisphere. Hence, Panama has onshore winds at the Atlantic coast, and winds from land to ocean at the Pacific coast most

Table II-3. Rainfall Totals (mm)

	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
Balboa Harbor - Pacific (65 yrs)													
Maximum:	127.0	127.0	127.0	203.2	381.0	406.4	406.4	406.4	431.8	533.4	533.4	381.0	2362.2
Average:	127.9	15.2	15.2	76.2	198.1	198.1	185.4	195.6	190.5	259.1	251.5	137.2	175.1
Minimum:	0	0	0	0	50.8	50.8	76.2	25.4	50.8	76.2	76.2	0	1244.6
Gamboa - Mid-Isthmus (79 yrs)													
Maximum:	330.2	127.0	101.6	304.8	508.0	482.6	533.4	508.0	482.6	660.4	787.4	635.0	3454.4
Average:	38.1	17.8	15.2	76.2	264.2	243.8	251.5	269.2	248.9	312.4	307.3	157.5	2204.7
Minimum:	0	0	0	0	76.2	76.2	101.6	101.6	101.6	152.4	76.2	25.4	1574.8
Cristobal Harbor - Atlantic (94 yrs)													
Maximum:	482.6	304.8	228.6	558.8	635.0	787.4	711.2	685.8	584.2	1066.8	1092.2	863.6	4648.2
Average:	83.8	40.6	38.1	101.6	315.0	335.4	396.2	388.6	317.4	398.8	571.5	309.9	3276.6
Minimum:	0	0	0	0	50.8	152.4	101.6	152.4	76.2	152.4	177.8	25.4	2184.4

of the time. Wind moving against a coast is forced upward because of convergence caused by increase of friction. Air moving upward cools because of decrease of atmospheric pressure. Clouds form when the dew point is reached; and, when the supply of fresh water condensate is greater than the air can hold, it rains. Additional factors result in a tendency toward intense, local showers rather than moderate, widespread rain. Rainfall decreases as the air moves across the Isthmus, losing its moisture. Figures II-5 through II-9 depict rainfall distributions throughout the Canal Zone.

Figures II-10, II-11, and II-12 illustrate differences in rainfall patterns on the two sides of the Canal Zone as a function of time of day. The hourly rainfall totals of the Atlantic side of the Isthmus show little variation in the course of a day as compared with the Pacific side. The totals and frequencies show maxima before sunrise and before sunset. The former are associated with the high intensities, the latter with the low. In sharp contrast, the Pacific has a strong rainfall maximum in the early or mid-afternoon. The time of the greatest frequency coincides with the time of the greatest intensity. Night rains are much less frequent at the Pacific during dry season than during the wet season; but, if they do occur, they are almost as intense as those in wet season.

E. SOLAR RADIATION

Day length in the Canal Zone is approximately 12 hours the year round with sunrise between 0600 and 0645 hours and sunset between 1750 and 1835 hours (Eastern Standard Time). Seasonal variations in solar radiation are caused more by changes in cloud cover than in day length. Monthly variations in global radiation at Pacific, Mid-Isthmus and Atlantic sites are shown in figure II-13. Information on the nature of this radiation for the Atlantic side is presented in figure II-14. Data collected at Pacific stations show the same features. Global radiation is the total solar radiation reaching the sensor. It is composed of both direct and diffuse radiation. Diffuse radiation varies little seasonally, and comprises a significant portion of total radiation year round. During the wet season there is less direct than indirect radiation. An hourly analysis of radiation data indicates that sunshine is more probable before noon on the Pacific side and Mid-Isthmus, and more probable after noon on the Atlantic side.

Partial cloud cover, especially during the wet season, produces extreme variability in solar radiation during the day as illustrated in figure II-15. These fluctuations lead to substantial temperature changes on surfaces of materials exposed directly to the sun (paragraph H, below).

The ultraviolet portion of the solar spectrum is a major factor influencing the photochemical breakdown of polymeric materials.

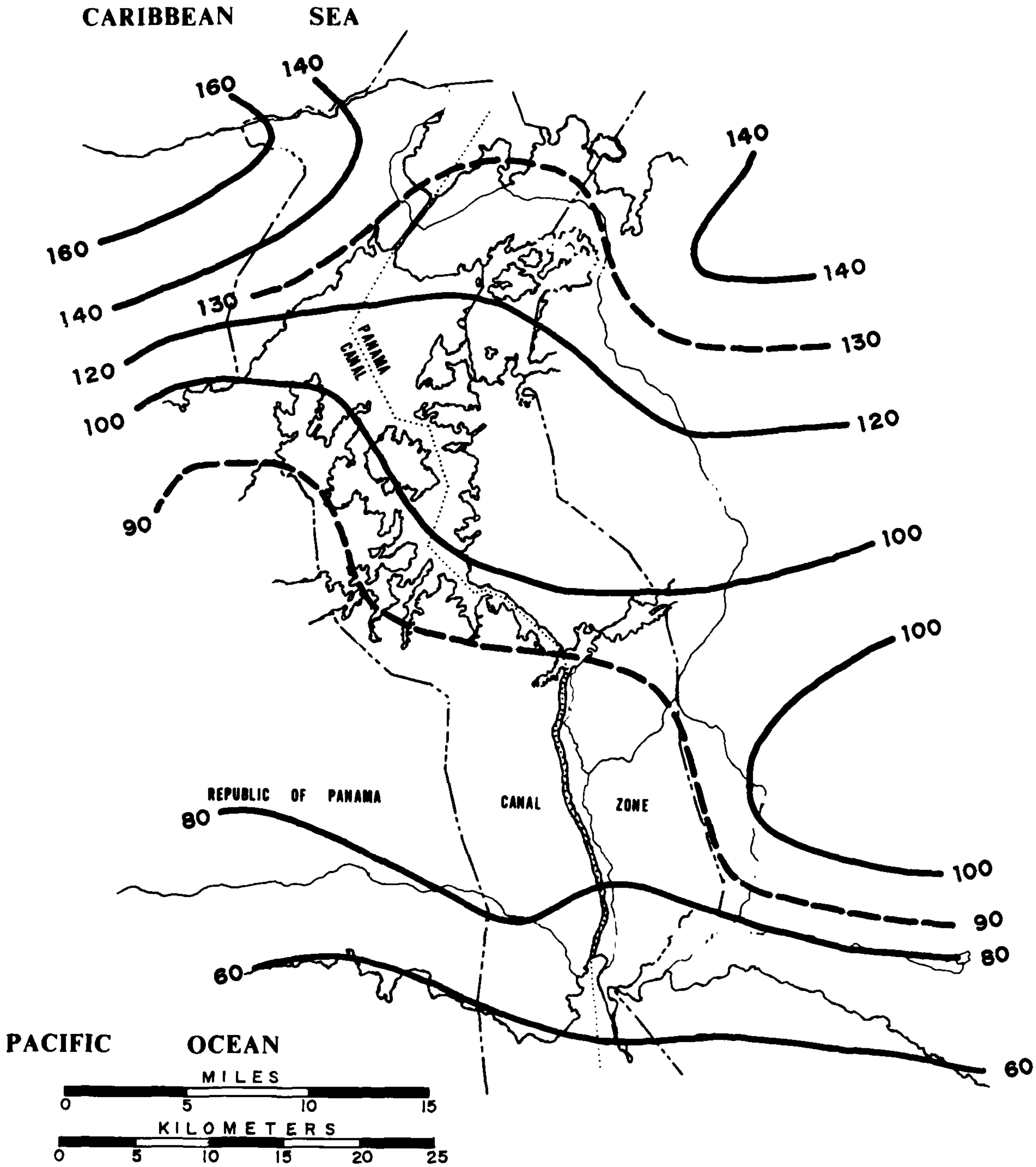


Figure II-5. Mean Annual Rainfall (Inches).

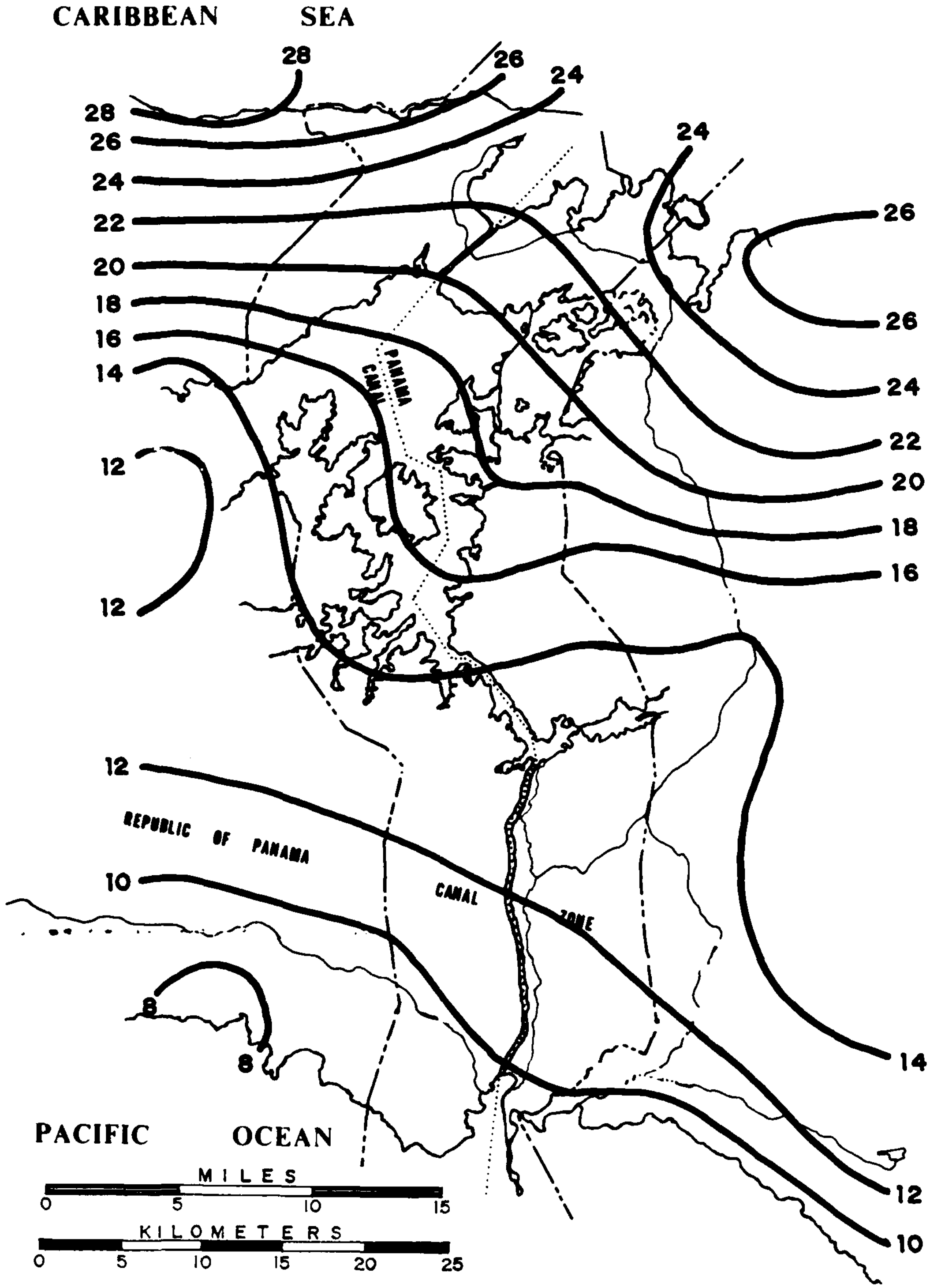


Figure II-6. Mean Wet Season (November) Rainfall (Inches).

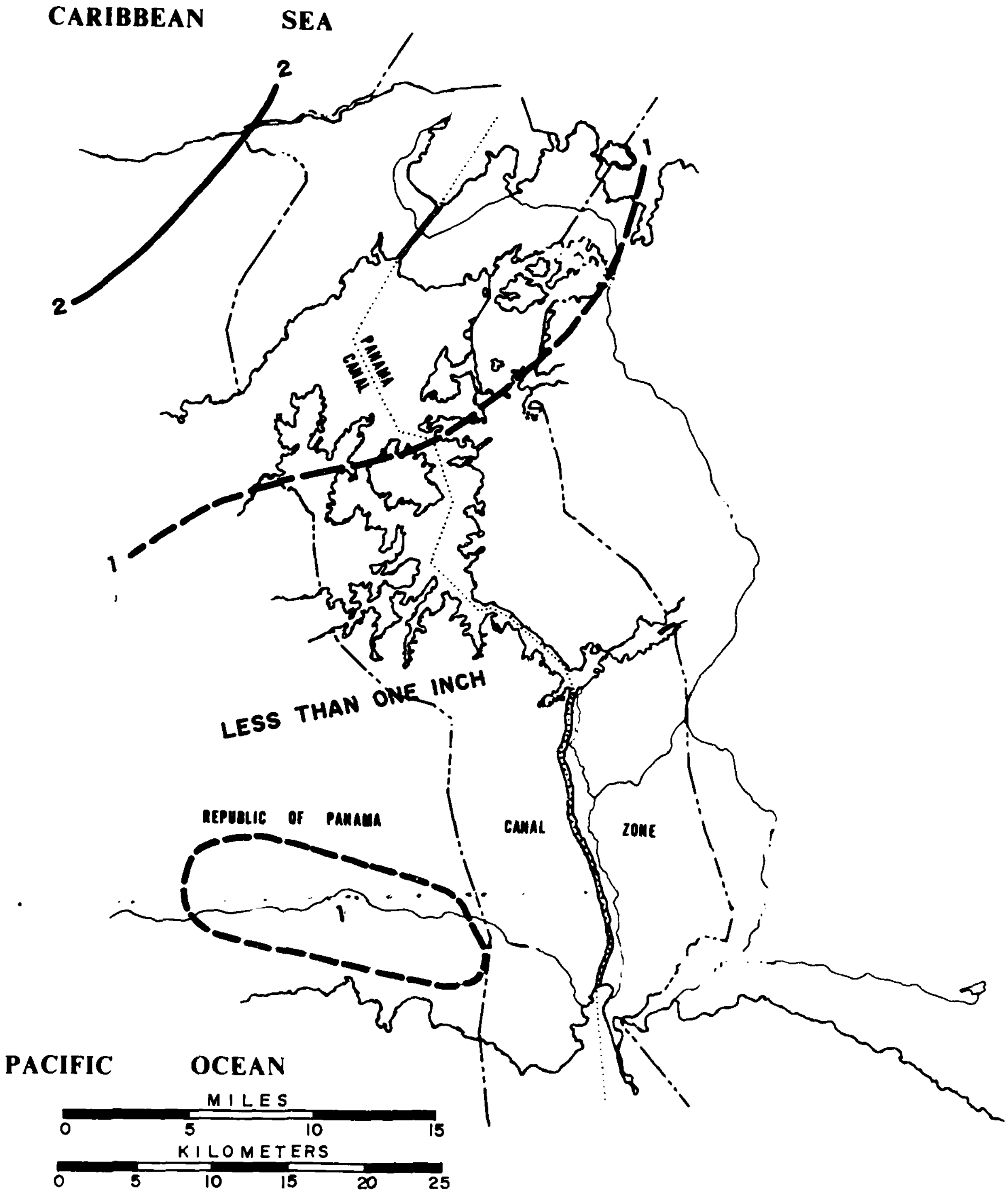


Figure II-7. Mean Dry Season (March) Rainfall (Inches).

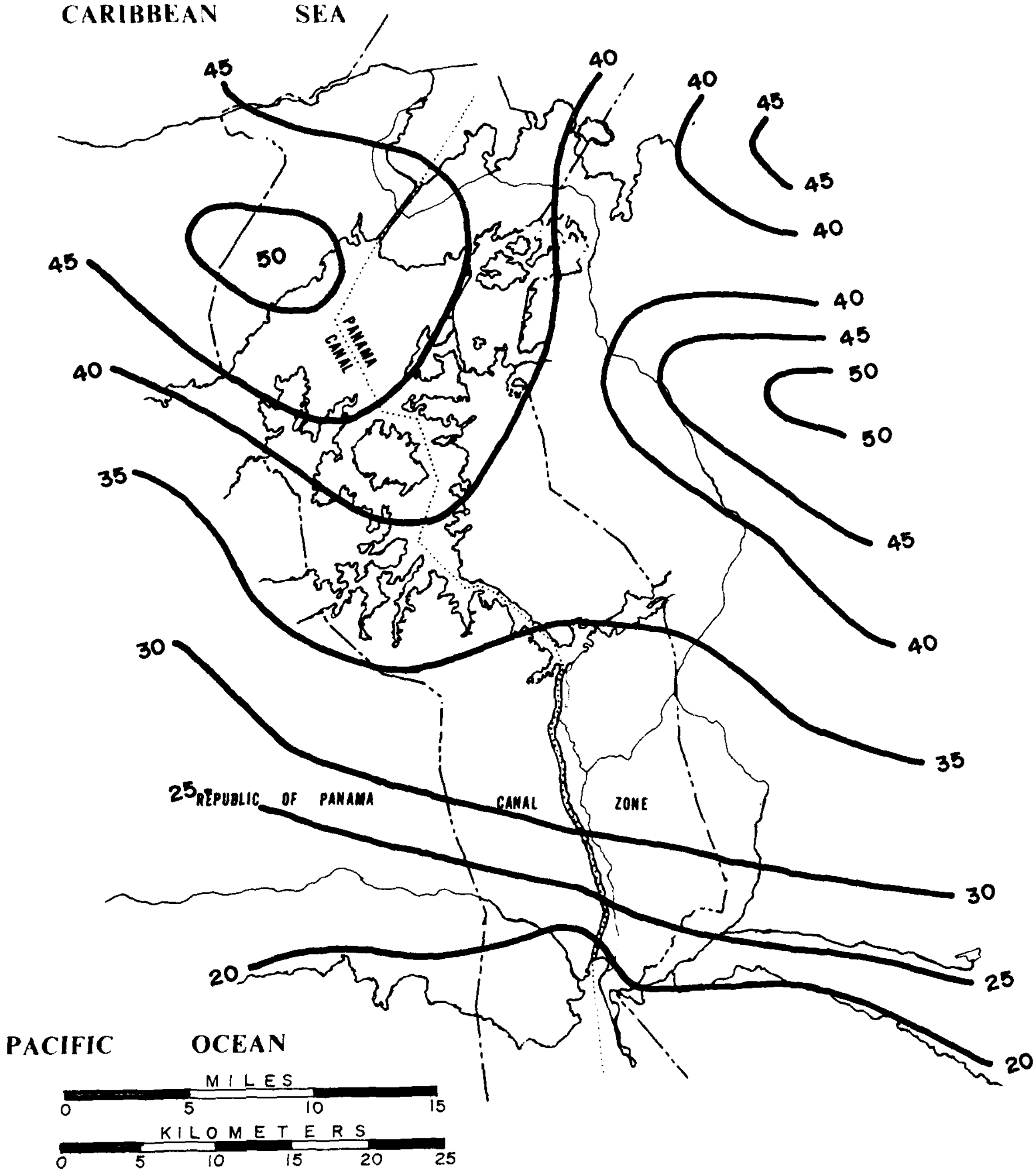


Figure II-8. Highest Total Rainfall for Any Calendar Month (Inches).

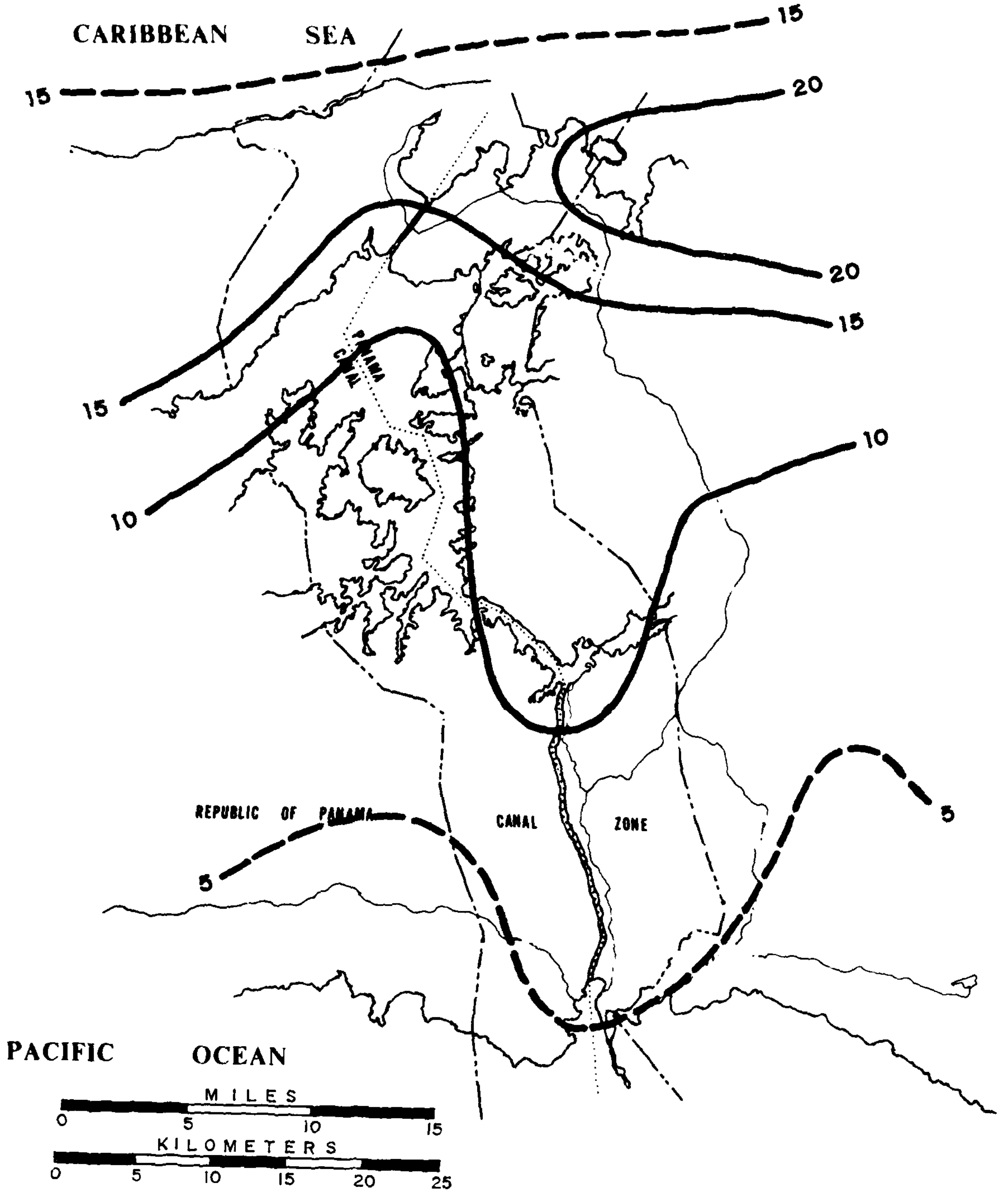


Figure II-9. Highest Total Rainfall for Any Dry Season Calendar Month (Inches).

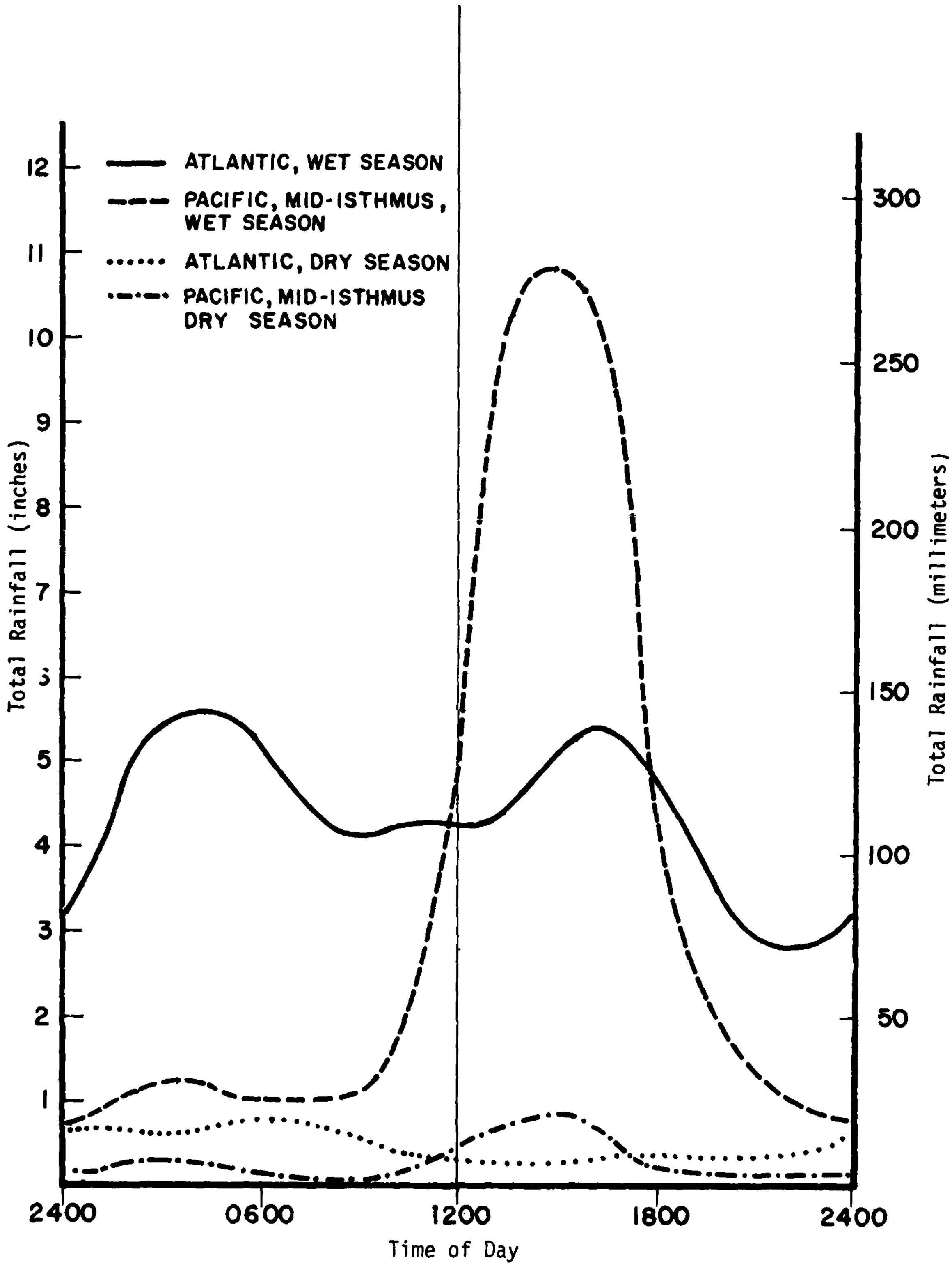


Figure II-10. Diurnal Variations in Total Rainfall per Season.

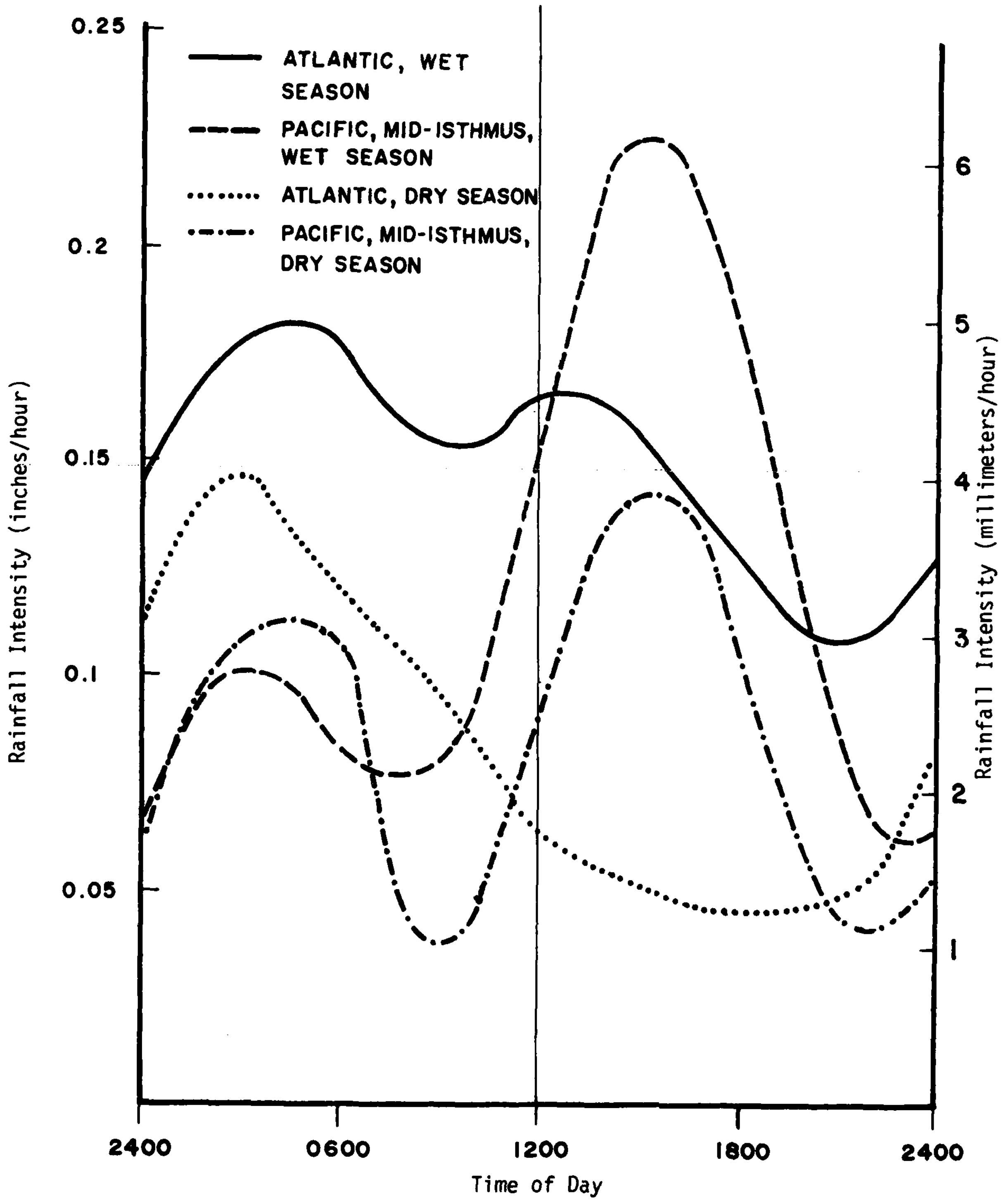


Figure II-11. Diurnal Variation in Rainfall Intensity.

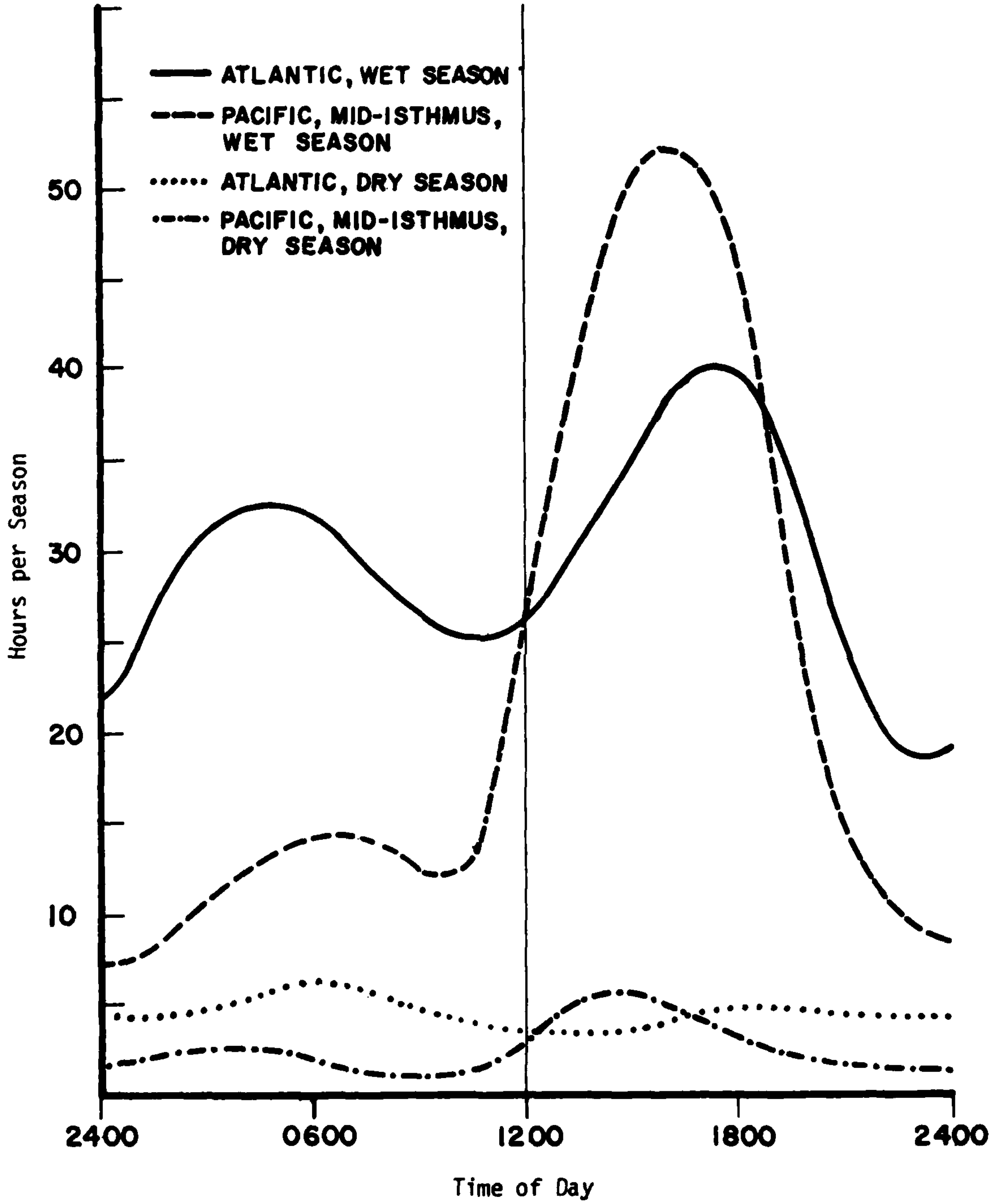


Figure II-12. Diurnal Variation in Total Hours Rainfall per Season.

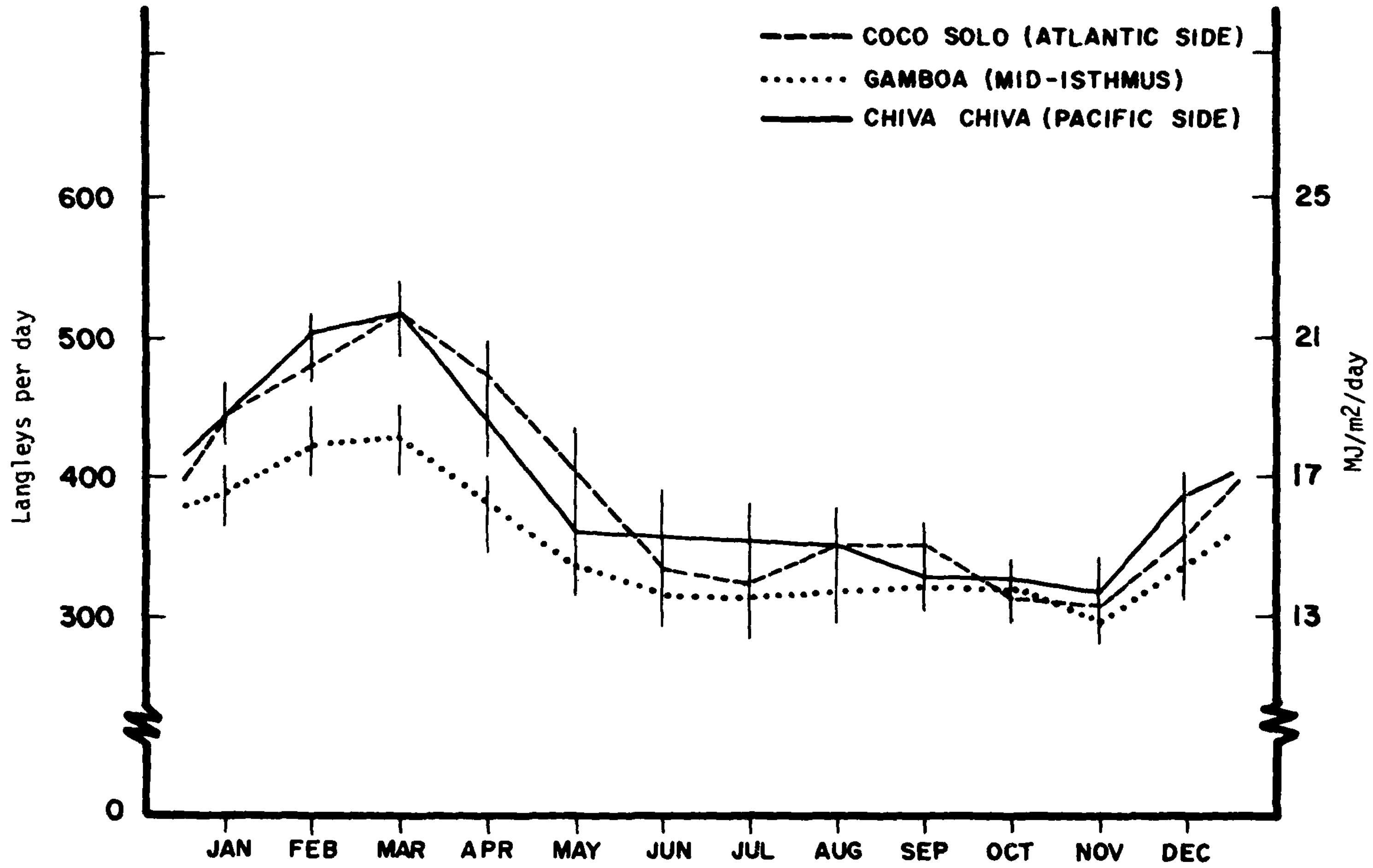


Figure II-13. Monthly Variation of Global Radiation

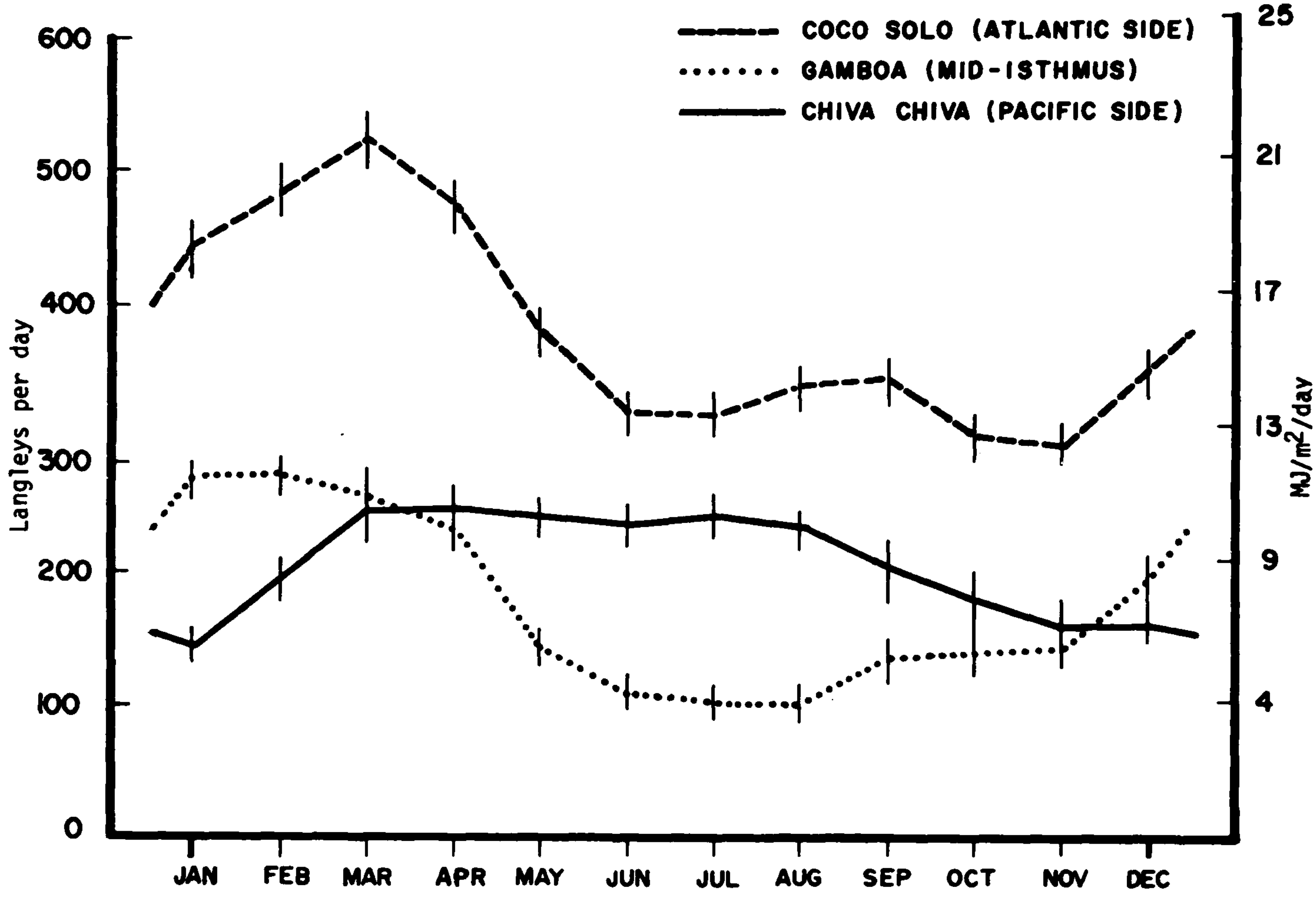


Figure II-14. Monthly Variation of Solar Radiation (Atlantic Side)

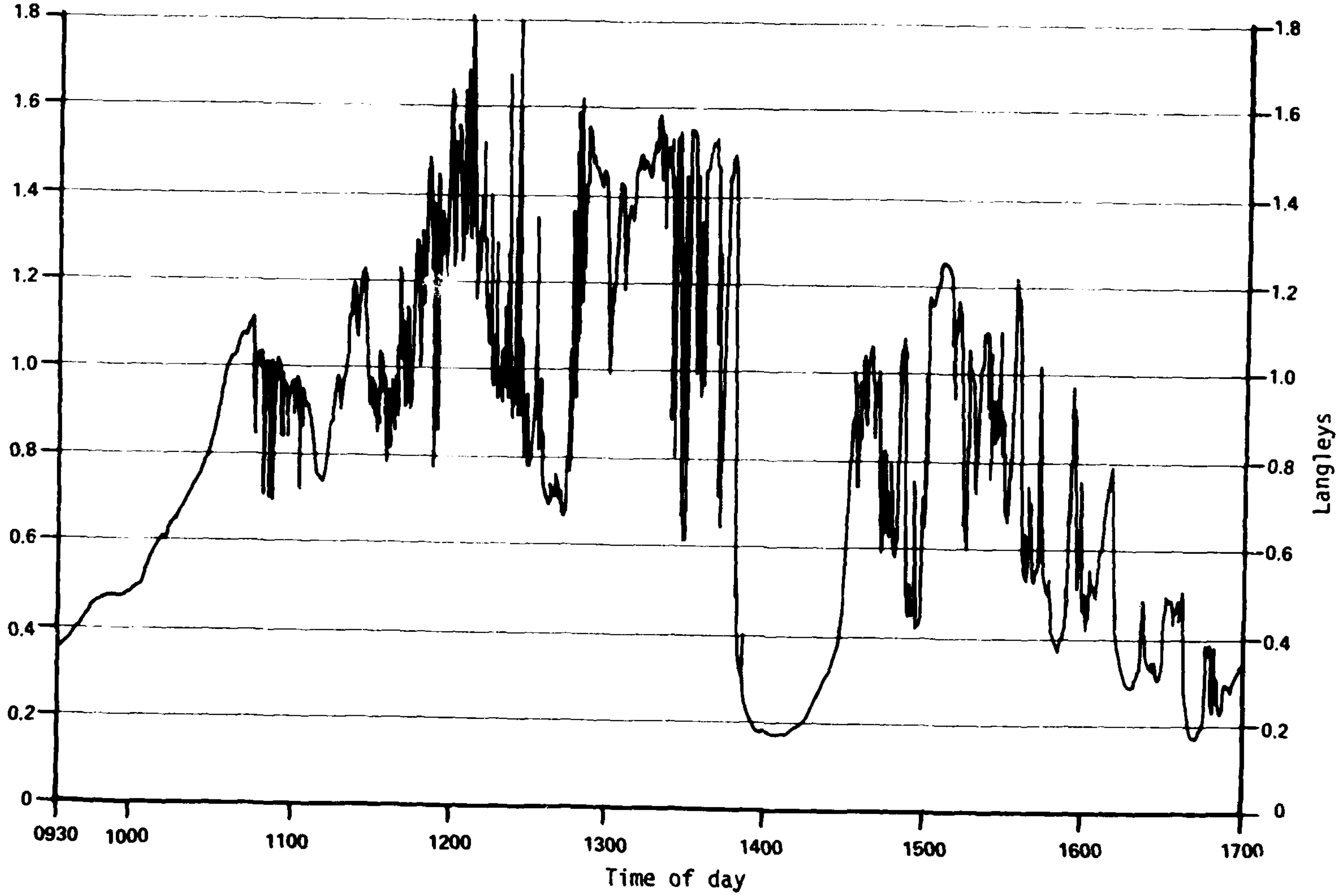


Figure II-15. Solar Radiation Measured on a Wet Season Day--Pacific Side of the Canal Zone

Estimated load in the ultraviolet and short wavelength visible spectral bands (285-390nm) for the Canal Zone is 8500 langleys per year. This compares with 10,000 langleys annually for Yuma, Arizona, and 3500 langleys for Walthan Abbey, Essex, England. The seasonal variation is much smaller in the Canal Zone than in Yuma. A horizontal surface in the Canal Zone collects approximately 20 langleys per day in the rainy season and 28 langleys per day in the dry season. Conversely, the extreme values in Yuma are 14 langleys per day in the winter and 28 langleys per day in the summer.

F. WIND

The Canal Zone is in or near the Atlantic trade wind belt for a considerable part of the year. However, these trade winds have traveled a great distance over water prior to interception by the Central American land mass, and thereby have lost impetus and are somewhat modified in character. The local and eastern Pacific wind systems frequently weaken, overcome, or replace the trade winds. When well organized, the Pacific winds are sometimes referred to as monsoon, the Atlantic winds as trade winds.

Frequently an area of light winds separates the Pacific monsoon system from the Atlantic trade wind system. This area is characterized by low clouds, frequent rains and muggy air and is referred to as the Intertropical Convergence Zone (formerly known as the doldrums). During the dry season this zone lies south of Panama. At the onset of the wet season, the zone begins to move back and forth across the Isthmus and continues this oscillation throughout the wetter months.

During dry season trade winds are dominant. Wind speeds of 15 miles-per-hour from the north northeast are normal at the Atlantic coast. The speed decreases rapidly inland and the winds veer, arriving as north winds at the Pacific coast. During the rainy season the wind speeds are generally quite low, calms are frequent, and wind direction is variable. Occasionally the pattern is broken by gusts at the onset of thunderstorms.

The highest recorded wind speed, averaged over an hour, was 30 miles-per-hour. Local wind gusts have been of such intensity that they have uprooted trees, but widespread strong winds are not known in the Canal Zone. High surf may be observed on the Atlantic beaches during the dry season as a result of "norther" conditions on the open seas, or on either coast during the wet season as a result of distant hurricanes or earthquakes.

G. STORMS

Hurricanes with high winds never reach the Canal Zone; tornadoes, waterspouts, and hail are rare phenomena. The only storms of

significance are thunderstorms and temporals. Flooding is the most hazardous potential of both these types of storms, although damage from lightning and gusts cannot be ignored.

Thunderstorms are characterized by wind gusts at the onset, with local heavy rain and a decrease in temperature. Thunderstorms can last for several hours and cover a large area, or they can be of short duration and extremely localized. Very few rains are completely free of some electrical activity.

Temporals are less frequent than thunderstorms. These storms cover large areas and are characterized by evenly falling rain, no strong wind gusts, little or no electrical activity, and a duration of many hours. Both temporals and thunderstorms can cause flooding; the former because of the duration of rainfall over a large area, and the latter because of the violence of the rainfall. Temporals may lower daytime temperatures below the nighttime minimum.

H. INDUCED CLIMATIC CONDITIONS

The environment experienced by items exposed in the tropic environment is often much different from that measured using standard meteorological techniques. This section will describe temperature and humidity conditions associated with containers and shelters.

Portig (1975) measured storage and surface temperatures of five structures in the humid tropics: a large ventilated warehouse, an ammunition bunker, an unventilated sheet metal building, a general purpose tent, and a transportation (CONEX) container. These are typical storage structures used by the Army in the tropics. Maximum temperatures measured at various points in the structures are summarized in table II-4. Table II-5 compares extreme storage and surface temperatures measured at desert (Yuma, Arizona), temperate (Cameron Station, Virginia), and tropic (Canal Zone) sites. A daily temperature profile of induced and ambient temperatures for the CONEX container is illustrated in figure II-16.

Solar induced temperatures inside the storage structures showed much higher variability than outdoor ambient temperatures except for the ventilated warehouse and the ammunition bunker. Although higher ambient temperatures were recorded during the dry season, the maximum storage temperature occurred during the wet season when the atmosphere was clear and wind speeds were low.

Subsequent works by Portig (1978) documented extreme surface temperatures and temperature fluctuations for structures in open exposure. The maximum temperature measured was 89°C in the air space between the metal roof and the insulation layer of a military-owned demountable container (MILVAN).

Table II-4. Absolute and Mean Maximum Temperatures--Five Storage Structures

	Absolute Maximum		Mean Maximum	
	Dry Season	Wet Season	Dry Season	Wet Season
	°C (°F)	°C (°F)	°C (°F)	°C (°F)
Warehouse				
Roof outside	61 (142)	71 (160)	56 (133)	52 (126)
Ceiling	43 (110)	45 (113)	41 (106)	37 (99)
In air current of ventilation shaft	39 (103)	43 (109)	38 (100)	35 (95)
1 meter below ceiling	35 (95)	34 (93)	35 (95)	32 (90)
2.4 meters above floor	34 (94)	34 (94)	33 (92)	32 (90)
Ammunition Bunker				
Near Ceiling	28 (83)	27 (80)	27 (80)	26 (78)
At eye level	28 (82)	27 (81)	27 (79)	26 (79)
Near Floor	28 (83)	26 (79)	27 (80)	26 (78)
Metal Building				
Roof outside	71 (159)	71 (162)	61 (141)	55 (131)
Roof inside	68 (154)	71 (160)	57 (135)	56 (133)
Air 1 meter below roof ridge	59 (139)	56 (133)	54 (130)	47 (116)
2.4 meters above floor	50 (122)	47 (116)	47 (116)	41 (106)
General Purpose Tent (Medium)				
Fabric outside	74 (166)	80 (176)	64 (147)	62 (143)
Air 45 centimeters below highest point	61 (141)	72 (162)	49 (121)	54 (129)
Center of inner airspace	59 (139)	55 (131)	47 (117)	44 (111)
CONEX Container				
Upper surface	70 (158)	69 (157)	55 (131)	54 (130)
Ceiling	61 (141)	67 (153)	53 (128)	51 (124)
Center of inner airspace	47 (117)	61 (123)	43 (109)	43 (109)

Table II-5. Extreme Storage and Surface Temperatures
(Extremes of Ambient Temperatures of the Same Day)

	INSIDE STORAGE TEMPERATURES	STORAGE		AMBIENT			
				Minimum		Maximum	
		°C	(°F)	°C	(°F)	°C	(°F)
I	Yuma, Arizona						
	Air 6 inches below roof of empty, closed boxcar	64	(148)	28	(82)	43	(110)
	Air 6 inches above floor of empty, closed boxcar	56	(132)				
II	Cameron Station, Virginia						
	Air 6 inches below roof of empty, closed boxcar	48	(118)	21	(70)	38	(101)
	Air 6 inches above floor of empty, closed boxcar	43	(109)				
III	Panama Canal Zone						
	Air 1 meter below roof ridge, metal building	59	(139)	20	(68)	33	(91)
		56	(133)	22	(72)	32	(90)
	Center of inner airspace, general purpose tent	59	(139)	21	(71)	33	(91)
		55	(131)	24	(75)	30	(86)
	Center of inner airspace, CONEX container	47	(117)	20	(68)	33	(91)
		51	(123)	22	(72)	32	(90)

	SURFACE SKIN TEMPERATURES	SURFACE		AMBIENT			
				Minimum		Maximum	
		°C	(°F)	°C	(°F)	°C	(°F)
IV	Yuma, Arizona						
	Thermometer fixed to upper surface of a stack of filled "C ration" cartons	57	(134)	20	(68)	46	(114)
	Soil surface	66	(150)	not known			
	Upper seam of a tent	72	(162)	not known			
V	Panama Canal Zone						
	Upper seam of a tent	74	(166)	21	(69)	32	(90)
		80	(176)	22	(71)	31	(88)
	Soil surface, March 1967	64	(148)	20	(68)	35	(95)

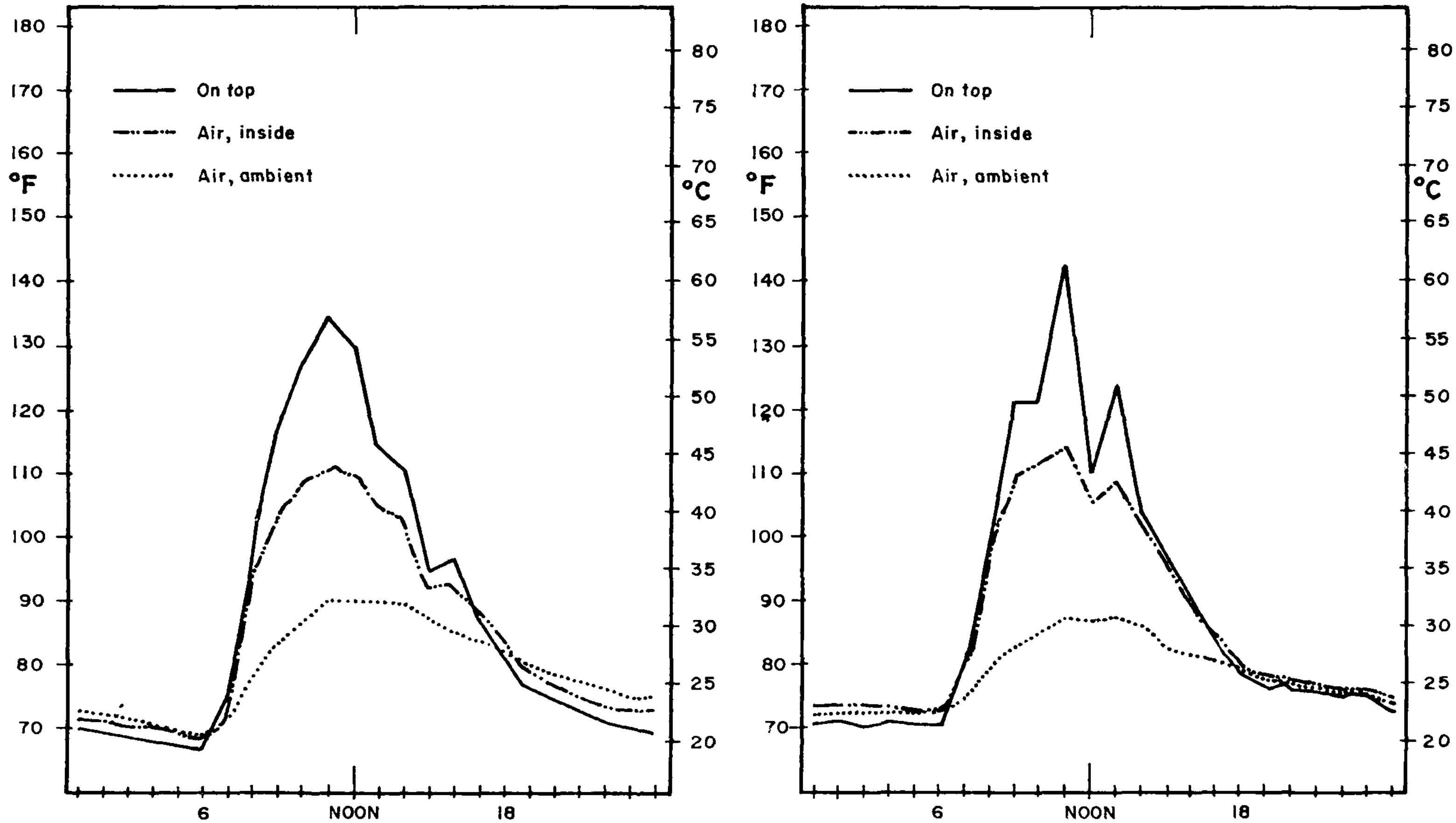


Figure II-16. Temperature Profiles, CONEX Container, Average for Five Hottest Days of the Study

Data were collected during the wet season (4 through 21 July 1976) and recorded at 90-second intervals. The maximum rate of change between readings was 6.7°C per minute. All extreme temperature fluctuations occurred between 1100 and 1400 hours and were caused by rapid changes in cloud cover or by contact with sudden rain showers. Large temperature fluctuations were common, occurring frequently during the course of a day as illustrated by figure II-17.

In the same study, Portig examined moisture conditions inside closed storage containers and found that a significant source of water vapor was from evaporation of water from the surfaces of materials stored within the container. Weight changes of the materials are shown in figure II-18.

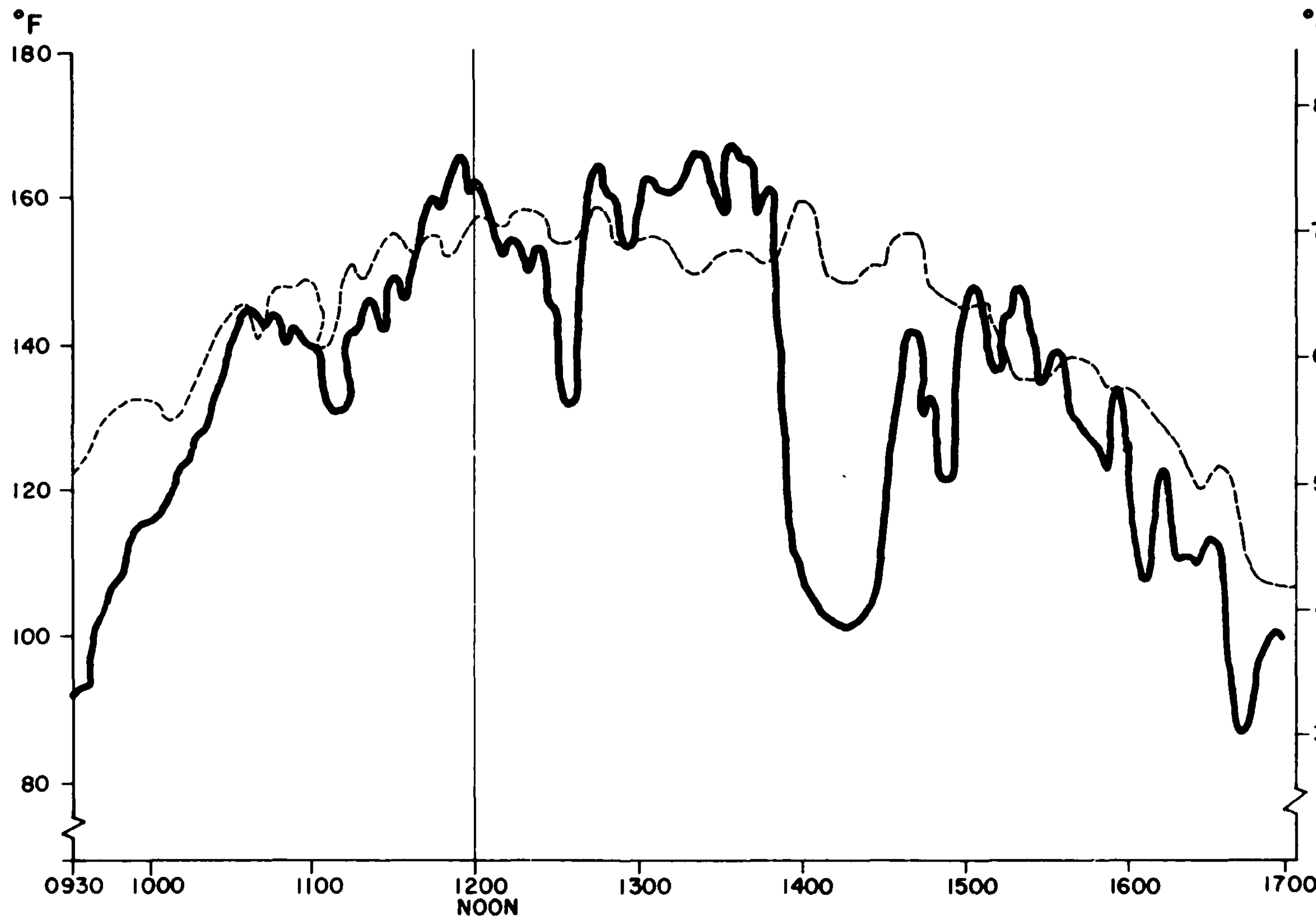


Figure II-17. Roof Temperatures, CONEX Container

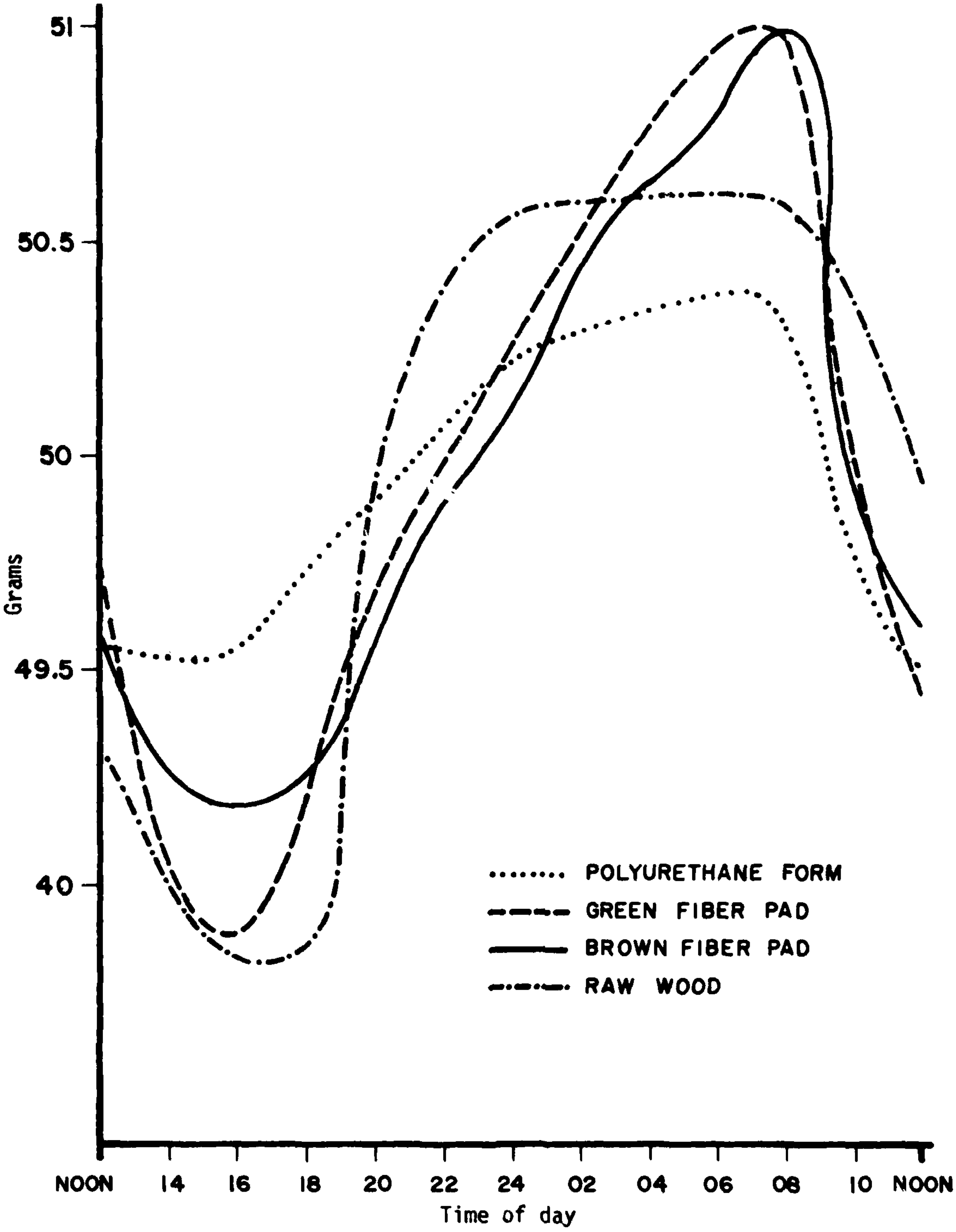


Figure II-18. Diurnal Change of Weight of Materials in a CONEX Container

SECTION III. PHYSICAL CHARACTERISTICS

A. INTRODUCTION

Characteristics of terrain factors such as topography, soil type and strength, and vegetation in quantitative terms are necessary to successfully conduct mobility/personnel movement (combat activity), propagation of electromagnetic energy, airdrop, and target acquisition tests.

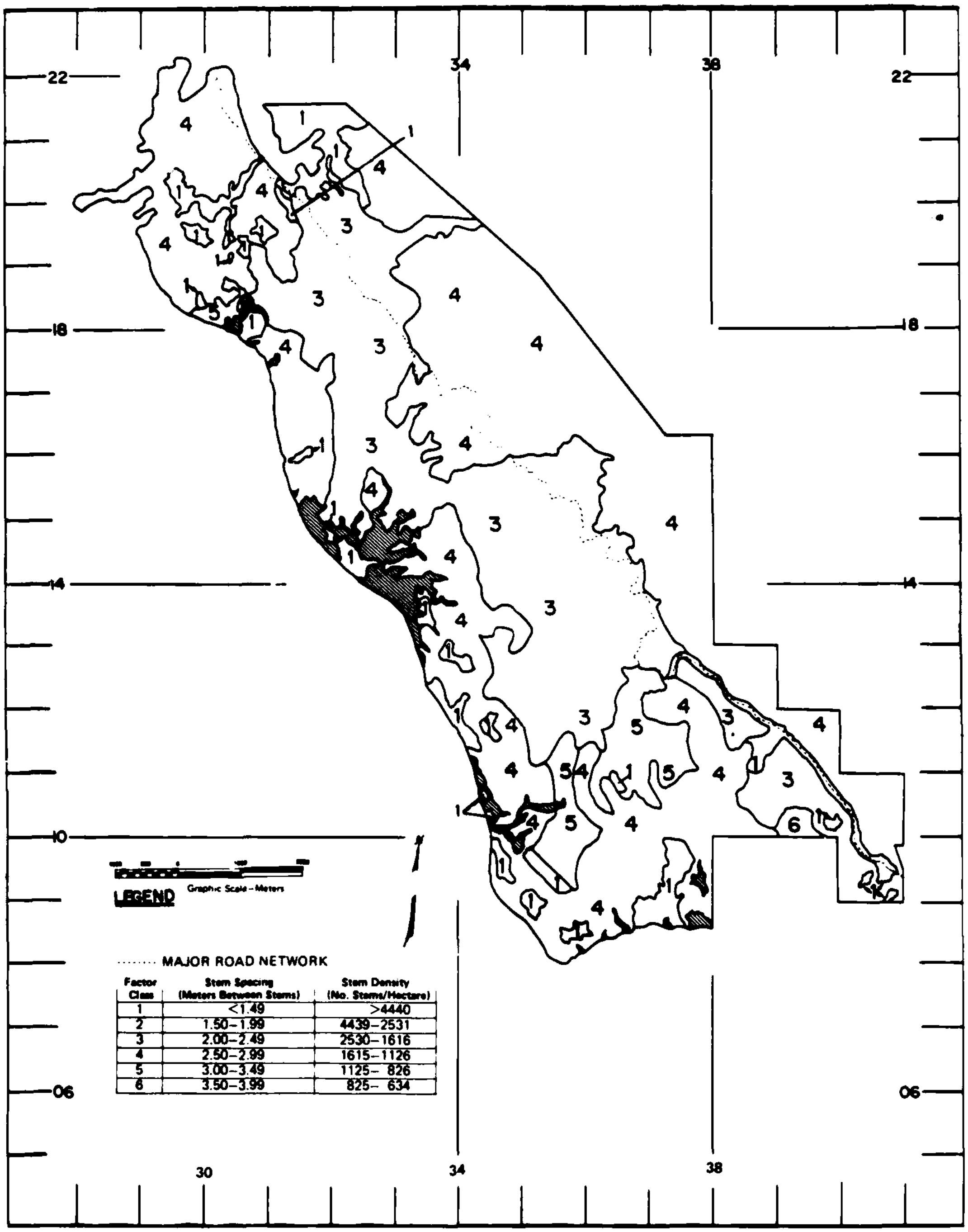
In FY72, the Tropic Test Center initiated an intensive field data collection program in all areas of interest from a testing viewpoint in the Canal Zone (Davis, et al., 1975, and Davis, et al., 1976). This program provided sufficient data to determine the range in variation of the terrain factors identified in the above paragraph, and permitted mapping of the areal distribution of these factors in a manner readily interpreted by test personnel. The formats selected for portrayal of the terrain were factor maps as shown in figure III-1. This map shows variations in selected classes of vegetation stem density in a section of one of USATTC's major test areas--Gamboa. Techniques for computerizing these factor maps for automatic selection of test sites most suitable for evaluating newly developed materiel items are discussed later in this section.

B. TOPOGRAPHY

The primary sources of topographic data were field data collection, topographic maps, and vertical aerial photographs. Figure III-2 shows boundaries of selected topographic slope classes characteristic of the Canal Zone. Other slopes exist within the unit, but the slopes shown are predominant.

C. SOILS

Soil properties influence the performance of many soldier/item activities and materiel undergoing exposure tests. Of primary importance to most activities is soil strength because it provides support for structures, resistance to explosive charges, support and traction for vehicles, and support for personnel on foot. The soil's physical, chemical, seismic and electrical conductivity characteristics influence the performance of materiel. All of these characteristics are modified by the tropic climate. The constant warmth (but not extreme heat) and abundant moisture are conducive to formation of lateric residual soils commonly classified as clay and silty clay according to the Unified Soil Classification System (USCS). Tropic soils do not exhibit the diversity of physical characteristics found in other climatic areas of the world; nevertheless, significant variations occur, frequently within short distances.



Factor Class	Stem Spacing (Meters Between Stems)	Stem Density (No. Stems/Hectare)
1	<1.49	>4440
2	1.50–1.99	4439–2531
3	2.00–2.49	2530–1616
4	2.50–2.99	1615–1126
5	3.00–3.49	1125– 826
6	3.50–3.99	825– 634

Figure III-1. Vegetation Stem Density--Gamboa

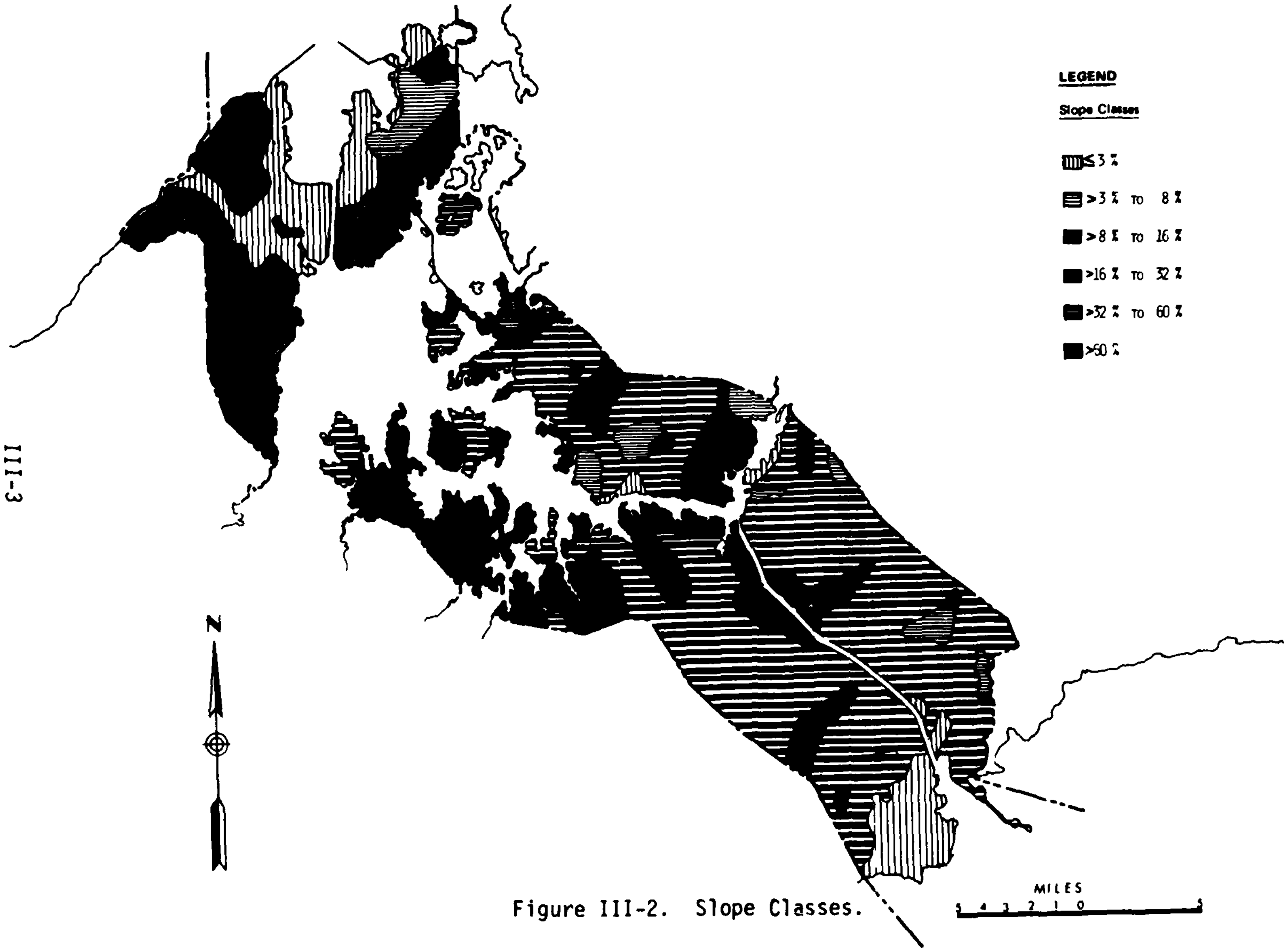


Figure III-2. Slope Classes.

General Properties

In tropic and subtropic regions, most soils are formed by laterization which consists of two separate processes, primary laterization and resilication.

Primary laterization is chemical weathering during which sodium, potassium, calcium, magnesium, and silica are depleted with a concurrent enrichment of the oxides of aluminum and iron in the soil. Such a process occurs under conditions of high temperature and unusually high rainfall on extremely well drained soils. The clay mineral content of these soils is very low; composition may be up to 90 percent free iron and aluminum oxides. Other chemical properties are a low cation exchange capacity, a low percent base saturation, and a low pH.

Silication is a chemical synthesis by which silica, that has washed out of the soil by primary laterization and accumulated as a result of imperfect drainage, combines with iron and aluminum oxides. Silication may occur near the water table level in soils below a zone of primary laterization, or near the surface in low-lying areas where drainage is impaired. The products of silication are clay minerals. Depending on the amount of silica available, the minerals formed may be either kaolinite or montmorillonite types. In the latter case, the soil is characterized by a high cation exchange capacity, high percent base saturation, a high pH, and a relatively low iron oxide content.

Although rainfall and temperature conditions are favorable to the process of laterization throughout most tropic and subtropic regions, soils other than laterites are common. Any major deviation from the required interrelationship among climate, vegetation, parent material, topography, and time can produce conditions that will cause other soil types to develop.

Analogy with Temperate Soils

Meyer (1966) conducted field and laboratory tests of 11 fine-grained soils in the United States and 17 fine-grained soils from tropic climates to determine analogies among them, and to determine relationships among the physical properties of soils and the horizontal variation of these properties *in situ*. Soil samples from the 6- to 12-inch depth were taken from sites in the Panama Canal Zone, Puerto Rico, Hawaii, and Thailand and were compared with similar samples taken in the United States. The comparison measurements included grain size distribution, specific gravity, organic matter content, soluble salts content, pH, moisture-tension and mineralogical and chemical composition data. Conclusions were that temperate and tropic soils of similar parent material and Atterberg limits generally have other engineering properties that are similar; therefore, these soils behave similarly when subjected to standard and special engineering laboratory tests. Temperate and tropic soils differed in the following respects:

Residual soils from tropic climates have higher specific gravities.

Residual soils from tropic climates have higher percentages of organic matter.

Soils from tropic climates, except for alluvial silts that have been compacted in the laboratory to field density and tested at 0- and 0.06-atmospheric tension, generally have higher moisture contents and percent saturations and lower densities.

Soils from tropic climates generally have higher void ratios and coefficients of permeability in permeability tests of soils compacted in the laboratory.

Soils from tropic climates increase in particle size upon drying.

Characteristics of Canal Zone Soils

In the Canal Zone, the soils (Bennett, 1929) are predominantly (about 90 percent) residual soils, formed for the most part from weathering of igneous rocks (basaltic, andesitic, rhyolitic in nature) and some sedimentary rocks (limestone, sandstone, shales, tufts). These soils occupy rolling to very hilly terrain. The extreme weathering in the humid tropic climate has produced lateritic soils that have a low ratio of silica to iron and alumina. The low silica ratio makes these soils highly friable, porous, and resistant to erosion. The principal soil groups in the Canal Zone are classified, according to the USDA, as Arraijan, Gatun, and Frijoles (figure III-3) and as silty clay (MH) according to the USCS. These soil groups occupy about two-thirds of the Canal Zone area and usually have a brownish-red surface (about 2 inches) clay layer which is high in organic content, blocky in structure, and friable when moist. The subsoil is often greater than 5 feet in depth, is red in color, is friable when moist, and has the texture of clay. Good internal drainage is provided by its blocky to crumbly structure. About 80 percent of these soils support mature secondary growth forest and the remaining 20 percent of the land is used for agricultural purposes.

McDaniel (1966) described the physical characteristics (table III-1) and soil properties (table III-2) of 16 Canal Zone sites.

D. VEGETATION

Natural plant growth in the Canal Zone is usually dense. When vegetation has a potential influence on the outcome of testing, a vegetation structural characterization is essential. This assures that follow-on tests are conducted at sites similar to the original site and allows a prediction of test item performance in other parts of the world where similar plant associations exist. Activities which are influenced by vegetation include: airdrops through the jungle canopy, mobility, radio frequency and radar signal propagation, surveillance dispersal of aerosols and smokes, and weapons effectiveness.

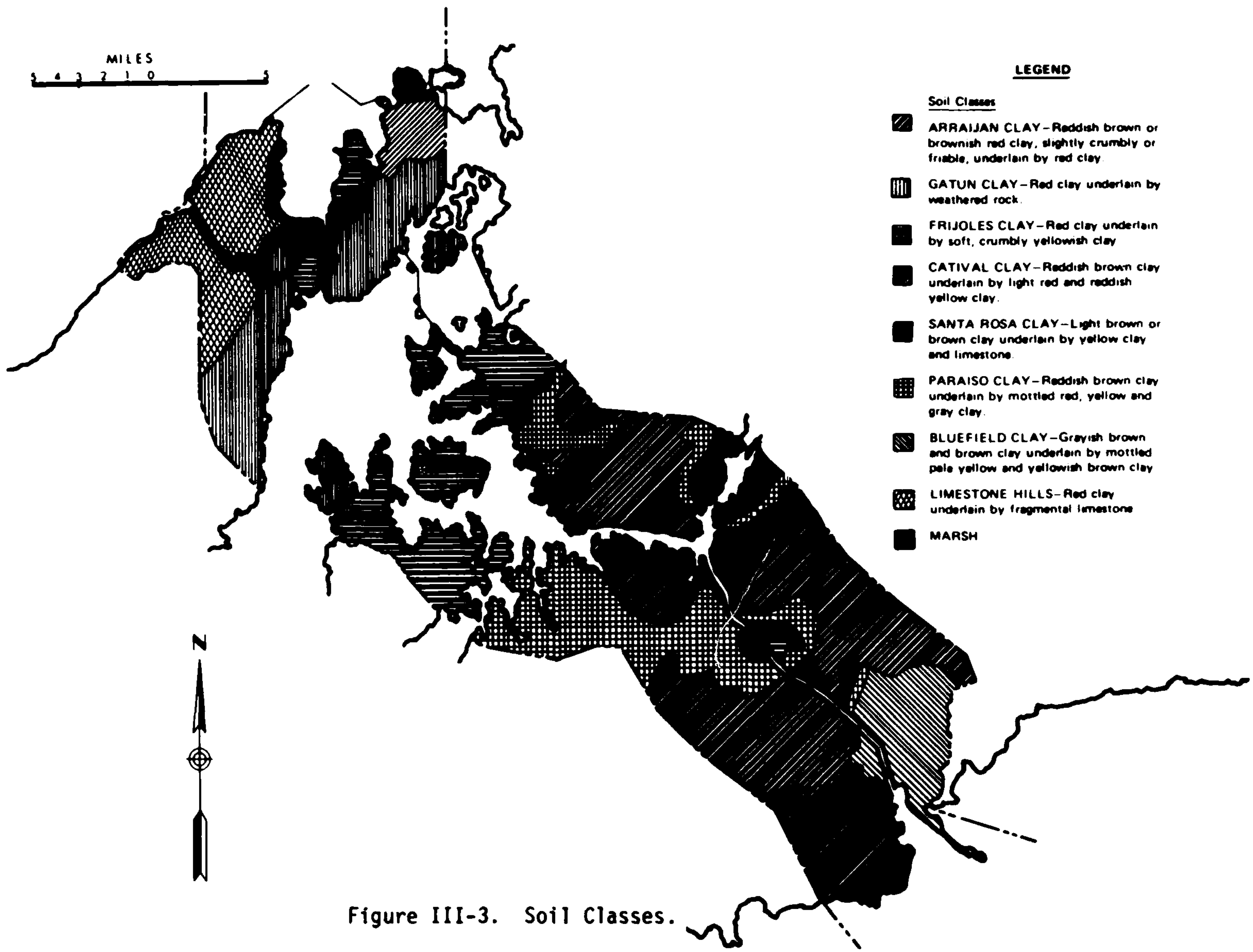


Figure III-3. Soil Classes.

Table III-1. Physical Characteristics of Canal Zone Sites (McDaniel, 1966)

Site	Location	Latitude	Longitude	Elevation ft msl	Topography: Parent Material	Topography: Aspect	Topography: Position*	Topography: Slope Percent	Drainage: Surface	Drainage: Internal	Vegetation
1	Albrook AFB	9°01'36"	79°32'14"	124	Tuff, agglomerate	Northwest	TF	2	Good	Medium	Forest
2	Chiva Chiva	9°03'01"	79°34'17"	174	Tuff, agglomerate	East	US	8	Good	Good	Woodland
3	Chiva Chiva	9°03'05"	79°34'17"	164	Tuff, agglomerate	East	LS	3	Fair	Poor	Tall scrub woodland
4	Ft Kobbe	8°54'27"	79°34'22"	66	Undifferentiated volcanic	West	TF	1	Medium	Medium	Forest
5	Palo Seco	8°55'47"	79°34'35"	7	Alluvial deposits	Level	BF	0	Poor	Poor	Woodland
6	Ft Clayton	9°00'23"	79°33'47"	102	Tuff, agglomerate	South	LS	5	Good	Good	Forest
7	Miraflores	9°00'06"	79°36'10"	66	Alluvium	Northeast	TS	3	Good	Good	Savanna
8	Ft Kobbe	8°54'07"	79°36'25"	43	Undifferentiated volcanic	West	LS	5	Good	Poor	Tall grass prairie
9	Ft Kobbe	8°53'31"	79°34'44"	10	Marine alluvial	Level	BF	0	Medium	Good	Woodland
10	Ft Clayton	9°00'18"	79°33'46"	66	Tuff, agglomerate	Southeast	TF	1	Good	Medium	Forest
11	Ft Kobbe	8°53'31"	79°35'40"	7	Marine deposits	Southeast	BF	2	Good	Good	Forest
12	Ft Sherman	9°18'39"	80°00'46"	16	Alluvium	Level	BF	0	Medium	Medium	Forest
13	Ft Sherman	9°16'53"	79°59'02"	276	Sandstone	North	US	11	Good	Medium	Forest
14	Ft Sherman	9°19'10"	79°57'17"	10	Alluvium	Level	BF	0	Poor	Poor	Forest
15	Ft Gulick	9°19'37"	79°52'27"	10	Gatun formation	Level	BF	0	Medium	Medium	Forest
16	Coco Solo	9°23'16"	79°51'12"	0	Marine deposits	Level	BF	0	Poor	Poor	Woodland

*T = terrace, F = flat, U = upper, L = lower, S = slope, B = bottomland.

Table III-2. Soils Properties of Canal Zone Sites (McDaniel, 1966)

Site	Soil Layer in.	US Department of Agriculture Texture Classification	Mechanical Analysis Percent Gravel	Sand	Silt	Clay	Unified Soil Classification System Classification	Fines Percent	Organic Matter Percent	Atterberg Limits LL	PL	PI	Dry Density pcf	Soil Moisture Content, Percent Dry Weight Atmosphere Tension Zero	0.06	15.0	Field max	Field min	Theoretical 100 Percent Saturation	Specific Gravity
1	0- 6	C	0	17	36	47	MH	86	3.54	89	46	43	65.0	62.2	53.6	33.1	54.5	31.5	60.1	--
	6-12	C	0	20	33	47	MH	84	1.65	77	42	35	79.2	40.6	39.6	30.1	41.6	27.8	42.7	2.77
2	0- 6	CL	0	24	47	29	MH	81	3.77	69	39	30	69.6	51.2	44.7	25.2	45.8	22.0	52.4	--
	6-12	C	0	23	36	41	MH	81	1.45	67	38	29	78.2	42.0	40.0	25.5	39.9	25.4	43.1	2.71
3	0- 6	C	1	19	37	43	MH	84	4.60	77	37	40	64.6	62.2	51.0	26.9	47.4	22.2	60.2	--
	6-12	C	1	21	28	50	MH	82	1.77	71	37	34	79.2	43.2	41.4	25.8	43.6	23.4	42.8	2.78
4	0- 6	CL	0	27	34	39	MH	77	5.50	93	44	49	60.4	67.6	55.8	31.9	62.3	25.0	67.3	--
	6-12	C	0	14	31	55	MH	88	3.62	79	40	39	77.6	43.8	42.1	29.1	43.1	26.2	43.7	2.71
5	0- 6	C	0	8	32	60	MH	97	3.13	96	43	53	63.2	69.2	63.2	33.2	--	20.6	62.0	--
	6-12	C	3	32	23	42	CH	70	1.65	70	25	45	68.6	57.6	54.0	21.9	--	14.9	53.9	2.70
6	0- 6	SiCL	0	19	45	36	MH	86	3.00	88	46	42	67.0	57.8	52.3	30.8	60.7	32.0	54.7	--
	6-12	CL	0	26	39	35	MH	80	1.15	73	35	38	75.5	46.2	45.3	25.4	50.4	30.7	44.8	2.64
7	0- 6	L	0	44	36	20	MH	63	0.95	53	35	18	67.7	54.2	38.8	26.2	40.0	18.1	56.2	--
	6-12	L	0	35	39	26	MH	73	0.55	52	32	20	82.6	36.2	30.2	26.7	28.0	22.2	39.4	2.75
8	0- 6	L	2	45	35	18	CL	59	1.77	33	23	10	87.0	31.3	25.2	12.2	31.2	9.0	34.4	--
	6-12	L	1	40	37	22	CL	66	1.33	32	22	10	91.4	28.8	24.6	12.5	26.1	12.6	31.4	2.70
9	0- 6	S	1	98	0	1	SP	1	0.25	**NP	NP	NP	87.6	30.3	5.8	2.0	29.6	3.8	35.7	--
	6-12	S	2	94	2	2	SP	4	0.38	NP	NP	NP	89.8	30.0	6.8	2.5	27.9	7.7	33.8	2.80
10	0- 6	CL	0	22	50	28	MH	84	3.00	82	42	40	66.8	57.4	52.2	31.4	50.0	31.6	57.1	--
	6-12	CL	0	21	41	38	MH	86	1.25	70	37	33	82.2	43.0	41.1	29.7	40.4	30.7	39.4	2.75
11	0- 6	S	4	90	4	2	SW	6	1.33	NP	NP	NP	70.6	50.6	16.0	4.2	15.3	4.7	51.2	--
	6-12	S	6	90	1	3	SW	6	0.62	NP	NP	NP	82.0	38.9	11.6	3.6	10.6	4.4	39.2	2.74
12	0- 6	CL	0	28	42	30	MH	88	4.90	106	55	51	54.5	76.4	66.8	41.0	66.7	41.3	78.0	--
	6-12	SiC	0	15	40	45	MH	94	2.35	110	54	56	65.2	58.0	54.7	42.0	54.2	43.8	59.2	2.71
13	0- 6	CL	0	26	36	38	MH	90	3.40	118	58	60	50.6	85.0	73.8	43.7	79.2	52.5	86.5	--
	6-12	C	0	13	32	55	MH	92	2.21	115	57	58	62.3	62.8	60.3	42.0	59.3	48.2	63.1	2.71
14	0- 6	CL	4	34	--	--	MH	72	4.70	115	58	57	59.4	71.2	64.3	44.1	87.6	41.2	67.7	--
	6-12	SiC	0	15	41	44	MH	89	4.70	119	60	59	63.6	64.7	62.4	46,5	81.7	49.0	61.6	2.74
15	0- 6	CL	0	24	45	31	MH	83	4.72	98	54	44	59.0	69.7	66.4	39.5	67.9	44.1	69.0	--
	6-12	SiC	0	17	42	41	MH	88	3.18	95	52	43	66.2	58.4	56.0	39.6	56.6	42.5	58.1	2.76
16	0- 6	--	--	--	--	--	OS*	--	32.00	--	--	--	--	--	--	139.8	--	--	--	--
	6-12	--	--	--	--	--	OS	--	29.00	--	--	--	--	--	--	122.3	--	--	--	--

* Organic matter - sand mixture.
** Non-plastic.

Classification of Vegetation

Vegetation in test areas is classified according to the Holdridge Life Zone classification system (Holdridge, 1971). This system is based on the theory that vegetation structure (type) is directly dependent on temperature and precipitation, with some modifications (termed associations) caused by other factors. The system works well for describing tropic vegetation.

There are five major life zones found in the Canal Zone (figure III-4) according to the Holdridge system. In descending order of land coverage the life zones are: Tropical Moist Forest, Premontane Wet Forest, Premontane Moist Forest, Tropical Wet Forest, and Tropical Dry Forest. Found in each of these life zones are various associations caused by nonclimatic factors:

Secondary associations: Areas recently cut, burned or disturbed by man in other ways (grasslands, Heliconia or Palmetto areas, jungle tangle).

Edaphic associations: Associations resulting from or influenced by factors inherent in the soil, i.e., flood plains, areas frequently inundated with fresh, salt or brackish waters, slope and ridge associations; and areas well drained with shallow soils (e.g., freshwater palm swamps, catival forests, mangrove swamps).

The following structural description of the life zones listed above are for mature forests in well drained upland associations.

Tropical Moist Forest

General: Tall multistratal semideciduous or evergreen trees.

Canopy: Trees 40 to 50 meters tall with wide crowns, slender trunks often with buttresses, and boles unbranched for 25 to 35 meters.

Subcanopy: Trees up to 30 meters tall with narrow crowns; palms are common to abundant. Density of subcanopy is variable depending on length of dry season and site factors.

Understory trees: Trees 8 to 20 meters tall with round to conical crowns.

Shrub layer: Dwarf palms and giant herbs with banana-like leaves to the shrub layer.

Premontane Wet Forest

General: Tall to intermediate semievergreen trees with two or three strata. Strata are not always easily distinguishable.

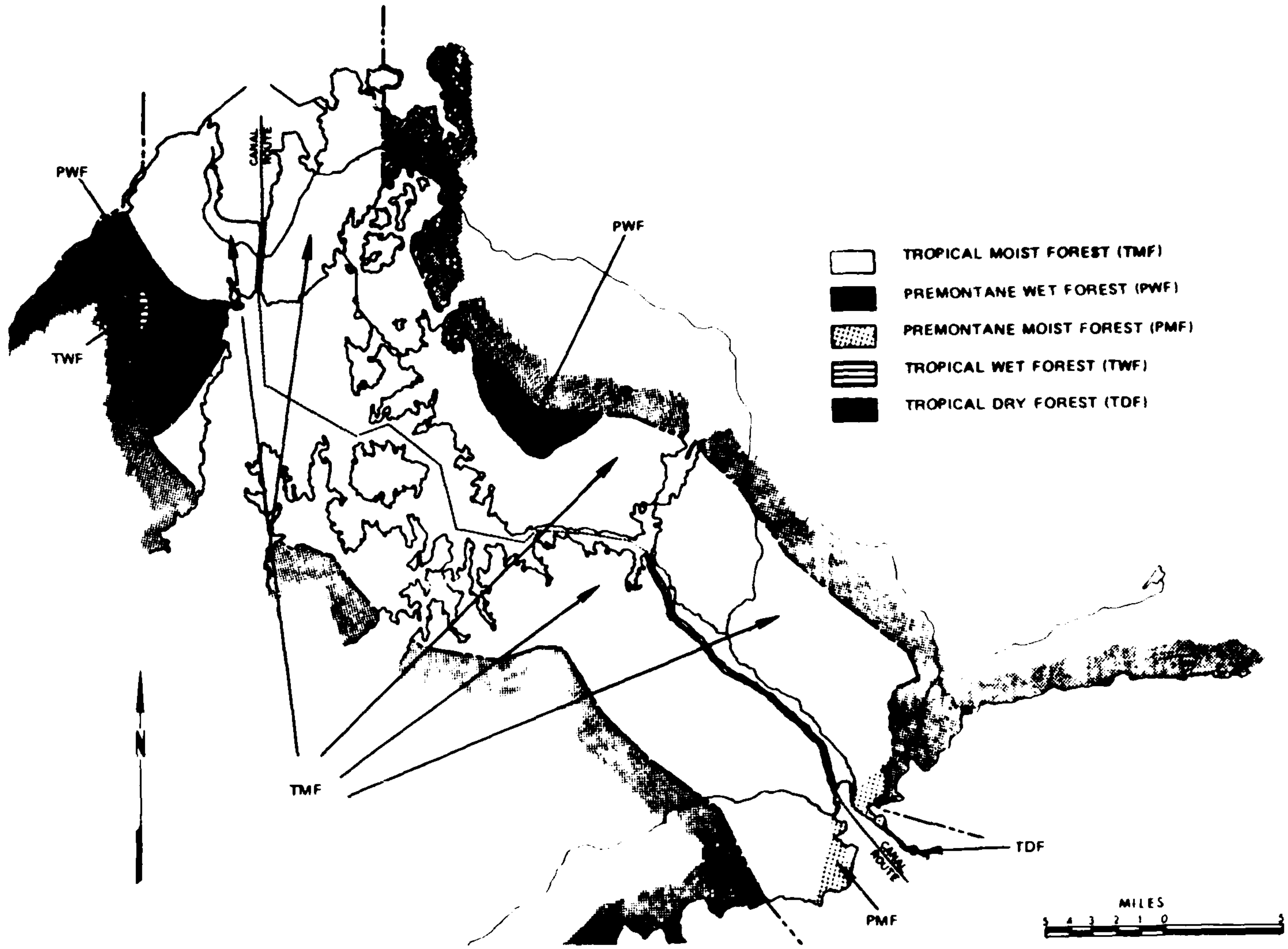


Figure III-4. Distribution of Forest Types (Life Zones) in the Canal Zone.

Canopy: Trees 30 to 40 meters tall with round to spreading crowns and slender to stout trunks. Buttresses are common but smaller than in Tropical Moist and Tropical Wet Forests.

Subcanopy: Small trees and shrub layers are evergreen.

Small-tree stratum: A dense layer of trees 10 to 20 meters tall. Stilt roots are common and tree ferns occasional.

Shrub layer: A dense stratum of single-stemmed small trees 2 to 3 meters tall; small palms are rare.

Premontane Moist Forest

General: Two-layered, semideciduous, seasonal trees of medium height. Canopy trees mostly deciduous; understory trees and shrubs, evergreen.

Canopy: Trees about 25 meters tall with characteristic broad flat or umbrella-shaped crowns, and short stout trunks sometimes with thorns.

Understory trees: Trees 10 to 20 meters tall, evergreen with round to conical crowns and short twisted or crooked boles.

Shrub layer: Dense woody plants, 2 to 3 meters tall, single and multistemmed, often with spines and occasional bamboo-like grasses.

Tropical Wet Forest

General: Tall, multistratal evergreen trees. A few canopy trees may be briefly deciduous especially when flowering. Number of tree species is very large.

Canopy: Trees 45 to 55 meters tall with occasional larger emergents. Crowns are round to umbrella-shaped, usually not in contact with each other. Clean boles up to 30 meters and high buttresses are common.

Subcanopy: Trees 30 to 40 meters tall fill spaces between upper canopy trees. Crowns, round; trunks, slender; large buttresses lacking.

Understory: Trees 10 to 25 meters tall with slender stems, often twisted or crooked; narrow conical crowns. Stilt-rooted palms are abundant.

Shrub layer: Dwarf palms 1.5 to 2.5 meters tall with undivided leaves usually abundant. Giant herbs with banana-like leaves are prevalent, especially in disturbed areas.

Tropical Dry Forest

General: Seasonally semideciduous trees of low to intermediate height with two-tree strata.

Canopy: Trees mostly 20 to 25 meters with widespreading, often flat-topped, crowns. Trunks are short, often strongly buttressed and occasionally armed.

Small-tree stratum: Trees 10 to 20 meters tall with slender, crooked, or leaning trunks and small open crowns.

Shrub layer: Shrubs 2 to 3 meters tall, dense only in openings; often with multiple-armed stems. Wood vines are common.

E. VEGETATION MEASUREMENTS

Blades (1972) of USATTC conducted a methodology investigation to determine the most accurate technique for predicting vegetation density of large tropic forest areas from data on small sample areas. Three methods were tested in this investigation. The first was the structural cell method which had been extensively used in RDTE investigations in which the effect of structural attributes are related to the performance of selected activities. The second was the modified random pairs method which had been employed by USATTC in a number of methodology and test projects. The final sampling technique was a modification of the quarter method. This method had not been applied previously to tropic forests in Army RDTE projects. The quarter method produced the highest absolute accuracy and was faster and easier to perform than the other two methods. The structural cell method consistently overestimated the density of tropical forest vegetation.

Data were collected in the above investigation that allowed the development of equations for predicting tree height from a tree diameter at breast height (1.37 meters)(figure III-5). These equations are particularly useful in dense canopies where measurement of tree height may be impossible. The equations, plus a detailed description of the modified quarter method of predicting vegetation density, have been published in TECOM Test Operations Procedure 1-1-052, Tropical Vegetation Measurements.

F. PHYSICAL DESCRIPTION

USATTC has test areas scattered across the Isthmus of Panama within the boundaries of the Canal Zone. A brief description of each of these areas is provided below.

Fort Sherman

There are four major types of terrain in the Fort Sherman area which is located on the Atlantic side of the Isthmus.

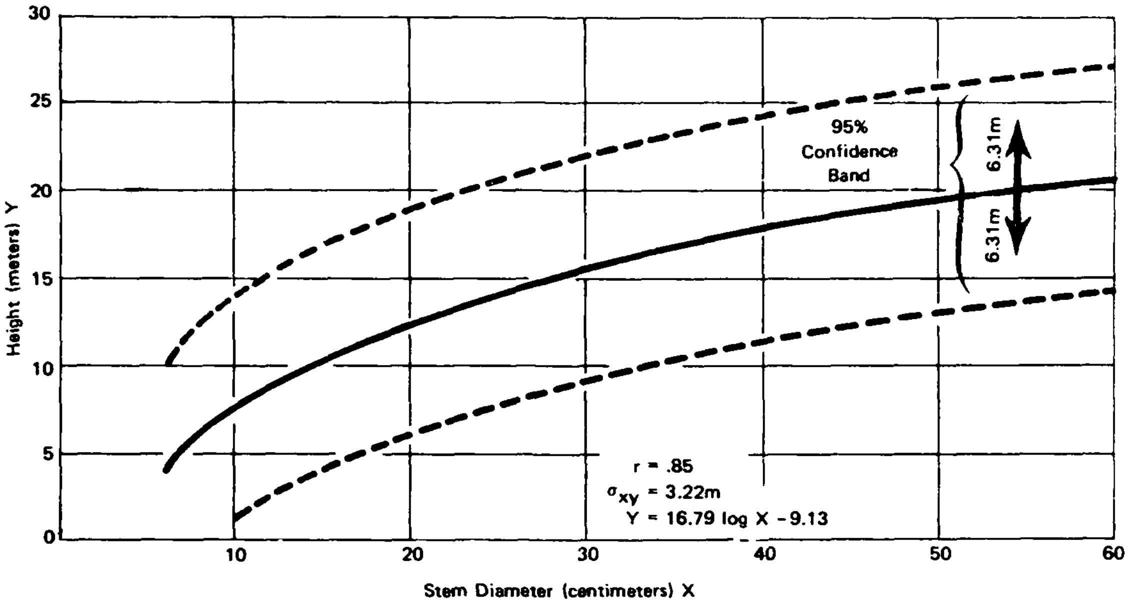


Figure III-5. Regression of Tree Height on Tree Diameter in Mature Tropical Wet and Mature and Immature Tropical Moist Forests

Undulating Uplands: These consist of dissected hills, 50 to 400 feet in elevation, slopes ranging from 8 to 32 percent, and many turbulent streams with fluctuating amounts of water traversing the area. Most of the soils are composed of clay throughout the profile. There are some small areas which have moderately fine-textured soil layers.

Drained Lowlands: These lowlands, below 20 feet in elevation, are systematically (artificially) ditched swamps and marshes. The soils are predominantly clay throughout the profile, but other soil textures occur in the flood plain of the Chagres River and in the drained areas. Medium and moderately fine soil textures dominate in the Chagres River flood plain, although in the drained areas soil textures are fine to moderately fine.

Undrained Lowlands: These lowlands contain the largest fresh water swamp in the Canal Zone. Soil textures are generally clay or silty clay with small local areas of coarser textures. Water stands over most of the area throughout the year. However, there are seasonal fluctuations both in depth and area covered. Soil strengths are always low in the swamp areas.

Coastal Fringe: This fringe extends from Fort Sherman east to the Chagres River and consists of short, covelike, sandy beaches,

separated by wave-cut cliffs, escarpments, and coral reefs. A continuous 1200-meter sandy beach lies southwest of the river's mouth. This beach varies in width from 25 to 50 meters and is backed by an unpaved road. Wave heights along the fringe are generally less than 1 meter, except during the dry season when they may be much higher. The diurnal tidal range averages 0.5 meter, resulting in a change in beach width of 5 to 10 meters.

The Fort Sherman area is classified in the Tropical Moist Forest life zone. A number of vegetation types are found in the area. In the mature forest (figure III-6) the canopy is irregular, multilayered and varies from 18 to 35 meters in height. Undergrowth is sparse except in scattered areas where sufficient light penetrates the canopy to produce moderately dense growth. This area has not suffered appreciably from cutting and burning so that the forests are nearmature. Second-growth forests which occur in limited areas are lower but more dense and tangled. Where saltwater penetrates inland, dense stands of red mangrove occur (figure III-7). These areas are composed primarily of prop-rooted trees of low stature which rarely reach 10 meters in height. Inland in brackish areas the white mangrove replaces the red, producing forests up to 22 meters in height. Black mangroves occur along with red and white in the transitional areas. Where low, marshy areas adjoin rising terrain, extremely dense stands of hibiscus are found. Poorly drained lowland areas support two vegetation types. A mature forest association occurs in areas with a high water table but with an absence of standing water. The forest association is characterized by an even-layered canopy about 30 meters high, canopy coverage approaching 100 percent, numerous epiphytes and large lianas, and sparse or nonexistent ground cover. In areas where standing water occurs most of the year, the vegetation consists predominantly of reeds and sedges except on slightly elevated hammocks where palms and a dense understory are found. There are a few grassland areas located on flat, recently disturbed terrain.

Gamboa Area

The Gamboa area (figure III-8) consists of dissected hills, the highest elevation being about 180 meters. Steep slopes are common, some being in excess of 60 percent. Ridges are sinuous, with narrow tops and long steep sides. Streams are closely spaced with a fine network of seasonal rills draining into numerous low gradient perennial streams.

Forests in the area are made up predominantly of evergreen trees with the remaining 30 percent of the canopy tree species being deciduous or semideciduous.* A large portion of the area has grown to a climax (mature) forest. The canopy of these forests reaches 28 meters with occasional emergents to 40 meters. The majority of tree species

*Semideciduous species lose the majority of their leaves only in severe dry seasons, but do not lose leaves in less severe dry seasons.

Figure III-6. Mature Tropical Forest

Figure III-7. Red Mangrove Forest

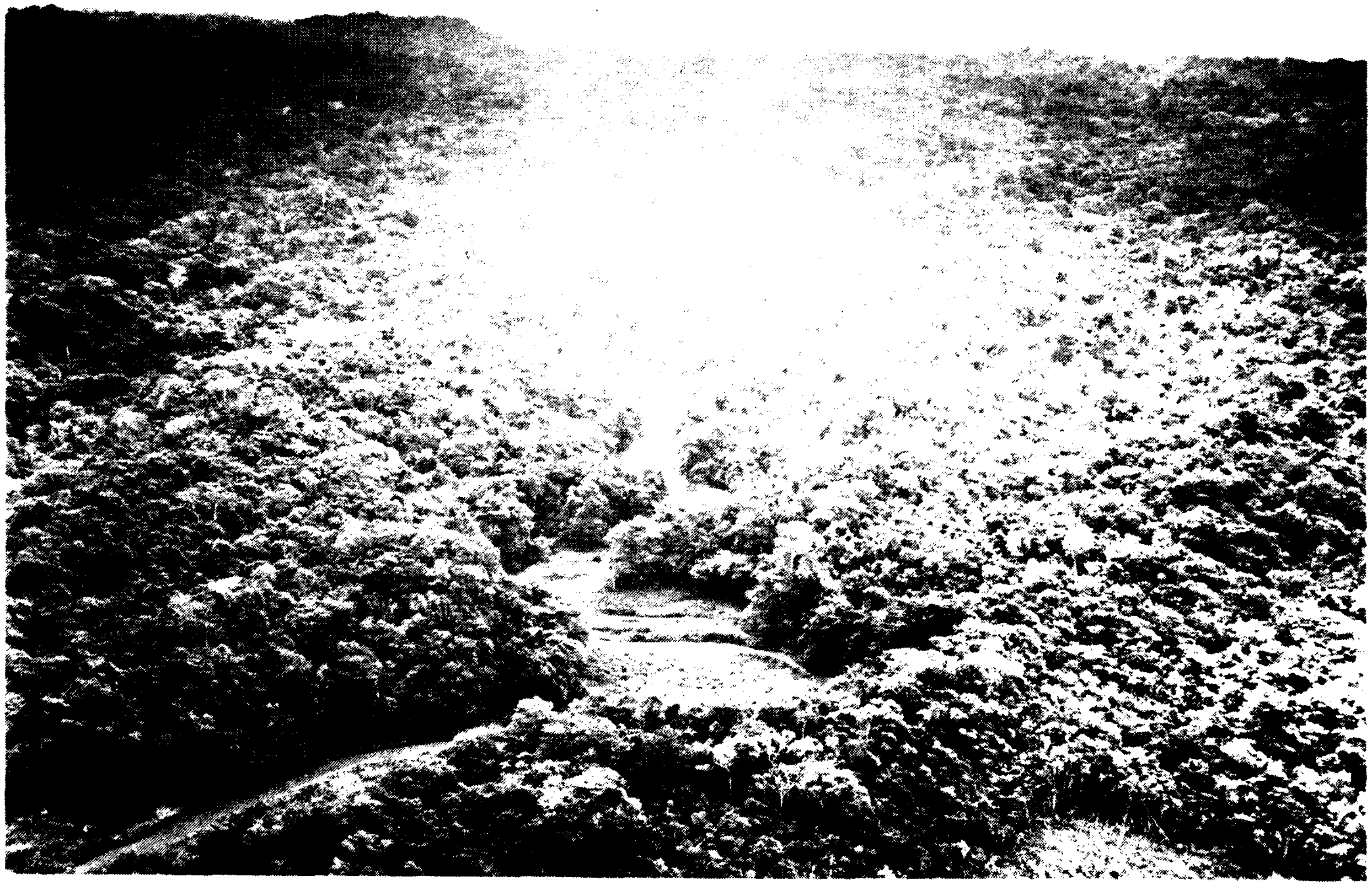


Figure III-8. Aerial View of Gamboa Vegetation.

have trunks to 60 centimeters in diameter at breast height, but some giants may reach 180 centimeters. The canopy coverage is usually greater than 80 percent with little undergrowth. During the dry season, personnel can move about under the canopy along a park-like forest floor. Sudden changes in relief, from deeply cut stream beds to sharply defined hills, are the principal deterrents to foot mobility. Changes in elevation produce variations in vegetation types, from the abundant Tropical Moist Forest to a cooler and wetter Premontane Wet Forest.

Areas of thick and tangled second-growth forest (figure III-9) occur primarily along the roads or in areas that have been disturbed in recent years. These areas have species that are shorter (up to 22 meters in height) and more deciduous. Vines, lianas, black palm, and climbing bamboo are prevalent along with dense stands of wild pineapple. Personnel movement on trails which are not used regularly is restricted to the speed at which the trail can be cleared with a machete. Areas that are burned repeatedly support pure stands of guinea grass, up to 2 meters in height, or grass mixed with wild banana (Heliconia sp). There are several of these stands, two in excess of 8 hectares in area.

Empire Range

The Empire Range and Rodman Ammunition Supply Point are situated on the Pacific slope of the continental divide and on the west side of the canal. The area (figure III-10) consists of a dissected hilly terrain with a summit elevation of about 180 meters. Generally, slopes are less extreme tnan those of the Gamboa area. Drainage lines are widely spaced, with low stream gradients. Rock outcrops are common on the steeper slopes. Soil depth varies; most of the area is composed of deep fine-textured soils consisting of clay throughout the profile. A portion of the area has shallow, clay soils underlain by rock at various depths. Reaction of both deep and shallow soils is from strongly acid to neutral. Areas of alluvium, ranging in texture from medium to fine, are found adjacent to the major streams.

The sharply rolling terrain, previous land usage, and mean annual rainfall of 200 centimeters combine to determine the appearance of the vegetation. The area shows evidence of having been cleared within the past 50 years, and as a result, the forest is not mature. The forest is a late-stage, second-growth association of the Tropical Moist Forest. Some large trees are relics left from former forests. Varying-aged, second-growth species have formed a broken and mixed stand, with an irregular canopy ranging from 12 to 25 meters. The irregularities of age are so pronounced that it is difficult to provide a single physical description of the vegetation. Canopy coverage may vary from 40 percent to 100 percent within a small area, and undergrowth from virtually none to an impenetrable tangle. A major cause of variation

Figure III-9. Second-Growth Forest.

Figure III-10. Aerial View of Empire Range Vegetation.

is the difference in soil depth and moisture content between the well drained ridge tops and the poorly drained valley floors (deep soil). There are also significant differences in rainfall within relatively small areas because of the effects of the sharp changes in elevation.

A majority of the canopy species are deciduous or semievergreen. This causes marked changes in horizontal target obscuration and visibility from the dry season to wet season. The majority of the forest has a well defined subcanopy of palms. Numerous small palms appear in the ground cover.

Fort Clayton General Purpose Test Area

This area, formerly the Chiva Chiva test area, comprising approximately 15 hectares, is situated on the Pacific slope of the Isthmus and on the east side of the Canal. The topography is relatively flat with some gently rolling terrain. Soils are deep and fine-textured with surface layers ranging from silty clay loam to clay. The reaction is slightly acid. The subsoil is dark brown to grayish brown, mottled clay, with reaction medium to slightly acid. Vegetation characteristics of the area are shown in figure III-11. About half of the area is covered with a continuous stand of mixed grasses and sedges which reaches a height of 2 meters. The remainder supports a late stage (50 years old), secondary-growth Tropical Moist Forest.

G. COMPUTERIZED TEST SITE SELECTION

Environmental factor maps (figure III-1) have been made for the Gamboa and Fort Clayton General Purpose test areas. A total of 45 factor maps were prepared on environmental parameters such as slope, forest type, vegetation type and stem density, soil type, soil strength, hydrologic features, and climatic categories.

Factor maps alone, although offering a convenient means of defining areas of homogeneity, are not always directly applicable to testing since the equipment under investigation is rarely influenced by a single environmental parameter. An example would be cross-country movement of vehicles influenced by topography and obstacles: vegetation stem size and spacing, and soil type and strength. To select appropriate test sites for cross-country vehicle testing, all factors must be considered in combination. Combining single factors to establish terrain factor complex maps is a complex task and can best be accomplished by computerized techniques. Computer programs have been developed that permit rapid retrieval of terrain factors for the two test areas. The single factor maps produced can be combined into factor complex maps, and the resulting data used as input to mathematical activity models that relate the influence of environmental factors on such military operations as vehicle and troop movement, and surveillance.

Figure III-11. Aerial View of Fort Clayton General Purpose Test Area.

Using these computerized techniques, USATTC can now expeditiously select test areas suitable for evaluating materiel in a range of available local environments. The computerized test site selection techniques developed are available for selecting sites for use in the tropic materiel test program.

SECTION IV. DEGRADING ENVIRONMENTAL FACTORS

A. MICROORGANISMS

If any group of organisms were selected as receiving the most attention with respect to deterioration problems, it would be the fungi. In general, this group of organisms exhibits rapid growth and a high level of diversity in warm, humid tropical areas.

The term fungus is a broad designation for a large, heterogeneous group of plants which lack the ability to fix carbon directly from the atmosphere. These organisms rely on breakdown of complex organic molecules to meet their nutritional needs. A large number of fungi obtain nutrients from dead plant and animal material, and then play an important role in complex biochemical cycles of soil formation and cycling of organic matter. In their role as decomposers, the fungi have evolved the metabolic ability to utilize a variety of organic molecules.

One mechanism of microbial damage arises from their ability to break down a diversity of organic compounds. Microorganisms can colonize susceptible materials and utilize them as food sources. Such attack usually results in marked deterioration of the physical properties of the material. Products of natural origin are most susceptible to this form of attack although certain synthetic polymers, plastic formulations and paints may also be affected.

A second mechanism of damage is indirect attack on materials. Fungi can grow on surface contaminants which find their way into materials during manufacture and use. The superficial growth can lead to damage of the underlying material even though that material is inert to direct attack. Many fungi produce metabolic waste products which may induce chemical/physical changes in the material. Even if superficial fungal growth results in no physical damage or loss of performance, it may affect the utility of the equipment for health reasons or by loss of confidence by the user.

The third mechanism of damage involves the effect of fungus on the operating capability of equipment caused by its physical presence. Optical paths can be blocked by growth on lenses and prisms. Accumulations of growth can block the movement of delicate moving parts. Fungal mats may cause unwanted conduction paths in electrical systems.

Teitell (1976) reported results of laboratory study of fungal effects on the electrical properties of electronic equipment. The results indicated that fungi will bridge wide insulating air spaces in electronic equipment (table IV-1). This bridging can cause "crosstalk" and other circuit defects. The low conductance of single

hyphal strands would be important only for extremely high impedance circuits, while large amounts of growth would be deleterious in many cases. Desiccation of the equipment nullified the conducting pathways formed, but subsequent exposure to high humidity re-established conductance (table IV-2).

Table IV-1. Electrical Conductance of Hyphal Strands

Air Space Bridged, mm	No. of Hyphae Bridging	Conductance Value Nanosiemens (nS)
	Mucor mucedo	
30	1	0.00005*
25	2	4
25	4	18 to 23
15	Large (5-day growth)	3,800
15	Large (21-day growth)	21,000
	Rhizopus arrhizus	
75	1	0.00007*
106	1	4
58	2	10
75	Several (6-day growth)	58
15	Large	1,100

*Only one value was obtained, which may be low because of poor contact. Other values in the table are reproducible and were obtained several times.

Table IV-2. Effects of Changing Relative Humidity on Conductance of Hyphae of *Rhizopus arrhizus*

Order of Exposure	RH in Vessel	Conductance nS
Step 1	100%	11
Step 2	11%	10^{-6}
Step 3	94%	4

Calderon (1968) presented results on fungi isolated from exposed missiles, soil and air in a Canal Zone semideciduous forest (table IV-3). Some organisms are commonly found in all three environments; however, a significant number are found primarily on the test item. These test-item-specific organisms are probably rare in the natural environment, but have special metabolic capabilities which allow them to colonize material contained in the test item.

Table IV-3. Percent of Samples Containing Specific Microorganisms

Microorganisms	Missiles	Air	Soil
Fusarium	100	81	85
Pullularia	100	0	0
Aspergillus	73	16	19
Nigrospora	73	2	2
Alternaria	64	0	10
Curvularia	64	11	3
Myrothecium	64	0	11
Penicillium	64	41	67
Hormodendrum	55	35	8
Spicaria	55	12	0
Cladosporium	45	0	0
Epicoccum	45	0	0
Phoma	45	0	25
Pyrenochaeta	45	0	2
Stemphylium	45	0	0
Chaetomium	36	0	1
Helminthosporium	36	0	1
Trichoderma	36	9	49
Pestalotia	18	0	0
Septonema	18	0	0
Sphaeronema	18	0	1
Stachybotrys	18	0	11
Streptomyces	18	20	24
Verticillium	18	1	1
Cephalosporium	1	32	0
Monilia	1	0.5	4
Gliocladium	0	41	3
Oidium	0	31	0
Rhinotrichum	1	6	0
Hyalopus	1	0	24
Masoniella	0	0	13
Pythium	0	0	10
Xylaria	0	0	10
Cunninghamella	0	0	9
Saksenaea	0	0	4
Mucor	1	0	3
Volutella	0	0	2
Ophiostoma	0	0	1
Bacteria	100	100	100

Calderon (1975) conducted studies in a tropical greenhouse to determine residual effects of fungus on Army materiel, which was periodically cleaned during normal inspection and maintenance, and to determine deleterious effects of fungus on materiel in areas inaccessible for periodic cleaning. Fungus growth was apparent on cotton strips and plastic conformal coating within the 1st-month exposure period. Corrosion was noted on steel metal strips after a 1-month exposure. Fungal growth on the surface of the cotton strips was easily cleaned off during the first 2 months; however, once it became established in the material it could not be removed completely. Periodically cleaned cotton strips showed a weight loss and a 40-percent strength loss after the first 6-month exposure period, while undisturbed (uncleaned) samples exhibited little weight or strength loss. After 14 months, both the undisturbed and periodically cleaned cotton strips showed approximately the same weight loss and 72- and 86-percent strength loss, respectively. Conclusions were that massive fungal growth on an organic substrate may not be indicative of biodeterioration. Periodic cleaning can be more detrimental to an organic substrate than fungal growth. Once fungal colonization occurs on a substrate, periodic cleaning will not remove the internal fungus. Periodically cleaned metal strips will corrode similarly to those inaccessible for cleaning when exposed to a tropic environment.

Bacteria are commonly found in the tropic environment but they are not considered as severe a threat to materiel as fungi since they require standing water for rapid growth. When water is present bacteria can cause extensive corrosion damage to metals and may be involved in degradation of other materials.

B. INSECTS

The most spectacularly destructive insects are the subterranean termites. Termite damage to both natural and synthetic materials has long been recognized as a serious problem. Cellulose-containing materials are especially susceptible to termite attack, but damage has often been reported to other organic material such as synthetic fibers, plastics, rubber and paints, or to inorganic substances. Species of the two dominant termite genera in Panama, *Nasutitermes* and *Coptotermes*, are known destroyers of wood, plastic material, and rubber. Another termite, less commonly found in the Canal Zone, is the dry wood termite which does less damage in comparison with the subterranean varieties.

A second group of insects not usually thought of as destructive to materials are roaches. They can do extensive damage to textiles and certain synthetic polymers such as silicon rubber. Even though roaches are not capable of digesting cellulose or silicon-based polymers, they can obtain nutritives from contaminants adhering to, or microorganisms growing on, the material. Figure IV-1 is a close-up of

insect damage on a silicon rubber-coated circuit board after 18 months of tropic exposure. The coating material was removed from about 15 percent of the circuit board surface. Fungal mycelia were common on the undamaged portion of the board but absent in areas where coating was removed. Insect damage on these boards had not been observed in temperate exposure.

Figure IV-1. Electronic Circuit Board Showing Cockroach Eggcase and Damaged Coating.

Many insects which do not attack materials directly may influence equipment performance through nest building activities.

C. AIR CHEMISTRY

Atmospheric Salt

The location of the Canal Zone between oceans only 56 miles apart results in high ambient salt levels. The high salt levels in conjunction with warm temperature and abundant moisture result in a very corrosive environment. For over 15 years atmospheric salt has been measured at several Canal Zone sites by the wet candle method. This method measures the amount of salt impinging naturally on a wet gauge wick. Figure IV-2 shows the monthly averages of salt collected on wet candles located immediately on the Atlantic coast (Fort Sherman breakwater) and inland at three sites across the Isthmus (Fort Sherman

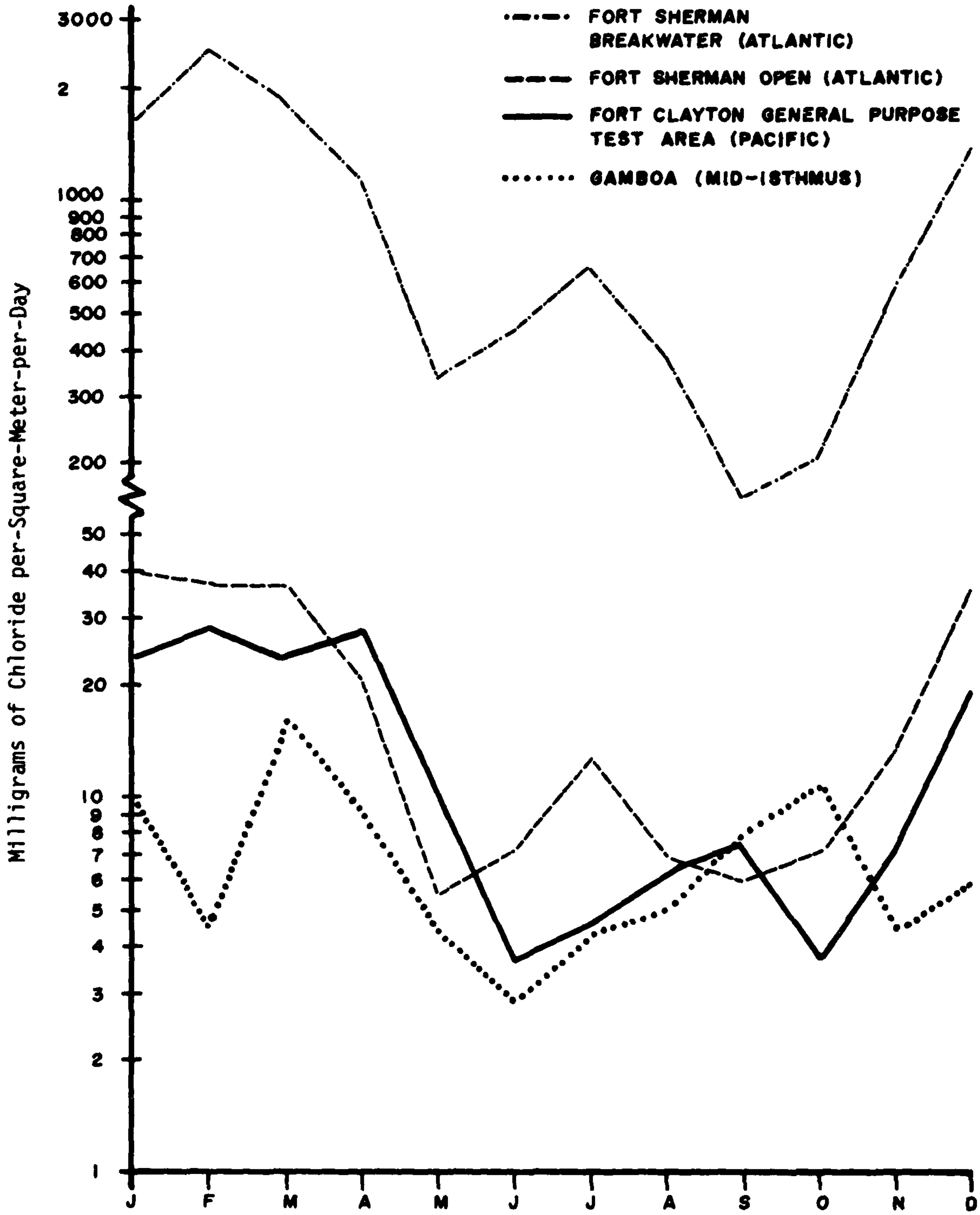


Figure IV-2 Atmospheric Salt Content Measured by Salt Candle.

Open--Atlantic, Gamboa--Mid-Isthmus and Fort Clayton General Purpose Test Area--Pacific). Atmospheric salt levels are highest on the Atlantic coast because of the action of the trade winds which blow from the north-northeast during the windy dry season (mid-December to mid-April). The fact that the Atlantic Ocean is the primary source of atmospheric salt is illustrated by accelerated corrosion of north-facing steel roofs in Panama City on the Pacific side of the Isthmus. The Fort Sherman breakwater site has been found to be one of the most corrosive natural environments available for testing materiel.

In 1973 a high volume air sampler was installed at the Fort Sherman Open Exposure Site. The sampler collects atmospheric salt by pulling a known volume of air through a paper filter. The filter is analyzed for total chloride content. The system allows measurement of salt concentration in the atmosphere. The methods provide comparable data in terms of monthly trends (figure IV-3).

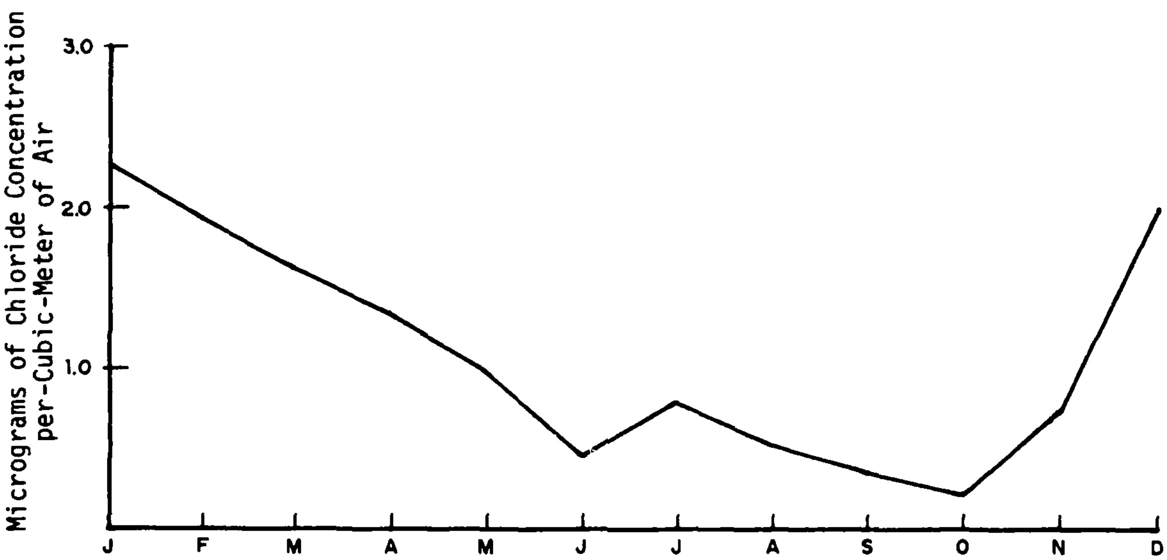


Figure IV-3. Atmospheric Salt Measured by High Volume Sampler (Fort Sherman Open Exposure Site).

Atmospheric Ozone

Atmospheric ozone is less then in the continental United States and Alaska. The mean and extreme ozone levels are lower than the smog-free areas of Arizona, Alaska and Massachusetts. The atmospheric ozone content in Los Angeles, measured during periods of smog, is more than 10 times the Canal Zone average.

Ozone content in the Canal Zone has a high correlation with wind speed which indicates that the ozone descends through turbulence from upper layers of the atmosphere and is not locally produced in the lower atmosphere. Greatest ozone content is observed in the dry season

when it averages 1.5 to 2 parts per-hundred-million. In the wet season it drops to 1 part per-hundred-million.

Terpenes

Sprouse (1974) conducted a research project at USATTC, sponsored by the US Army Materials and Mechanics Research Center, to identify ambient levels of organic compounds and determine their relationship to fungal growth and materials deterioration. Early work by Rasmussen et al. (1968) had suggested that organic materials, volatilized from the dense foliage of the humid tropics, might condense on material surfaces and provide nutrients for microbial growth. Microbial waste products might then damage the materials on which the growth occurred.

The study was conducted in two parts: a field phase which sampled seven test sites in the Canal Zone for volatile and condensed organic materials; and a laboratory phase which used controlled experiments to study relationships among selected monoterpenes, fungi, and material. The field phase of the study employed two methods to inventory the ambient organic compounds in the tropics. The first method used a non-polar, solid adsorbent air sampler to concentrate and collect ambient levels of volatile organic compounds. Measured compounds were predominantly petroleum and fossil fuel combustion products in concentrations of less than 5 parts-per-billion. Ambient levels of volatile compounds from vegetation effluents (monoterpenes) were not found in measurable quantities by air sampling. The second method collected condensed organic compounds by allowing their natural accumulation on field-exposed glass plates. These compounds were traced to tropic vegetation sources and the predominant component was identified as an aliphatic ester. The condensed organic compounds supported microbial growth both in the field and laboratory.

It was found that ambient levels of volatile organic compounds that derive their origin as vegetation effluents (monoterpenes) were not among the compounds measured in the Canal Zone tropics by the air sampling technique. The majority of the compounds measured were emissions from internal combustion engines and other fossil fuel uses. Ambient concentrations of the latter hydrocarbons were generally less than 5 parts-per-billion. Toluene was the most abundant compound measured (table IV-4).

Table IV-4. Volatile Organic Compounds Found in the Tropics of Panama

Compound	Concentration	Compound	Concentration
2-Methylpentane	3-5 ppb	o-Xylene	1-2 ppb
n-Hexane	2-3 ppb	Isopropylbenzene	1 ppb
Benzene	1-3 ppb	n-Propylbenzene	1-2 ppb
Acetone	1 ppb	Methylethylbenzene	1 ppb

(cont)

Table IV-4. (cont)

Compound	Concentration	Compound	Concentration
Toluene	2-5 ppb	Methylbenzene	1-2 ppb
Ethylbenzene	1-2 ppb	Trimethybenzene	1-2 ppb
m,p-Xylene	2-4 ppb	Benzaldehyde	1 ppb

*ppb: Parts-per-billion

Conclusions drawn from the investigation were as follows:

Diurnal measurements of volatile organic material by air sampling showed that ambient concentrations fluctuate throughout the day but the same hydrocarbons are always present.

Total volatile hydrocarbon concentrations were nearly equal on the Atlantic and Pacific sides of the Isthmus where pollution sources exist in greater frequency. The geographically more isolated Mid-Isthmus sites showed a lower total hydrocarbon concentration (figure IV-4).

The forest sites possessed a slightly higher concentration of volatile hydrocarbons than the grassland sites because the limited air circulation under the jungle canopy does not allow ambient gases to escape.

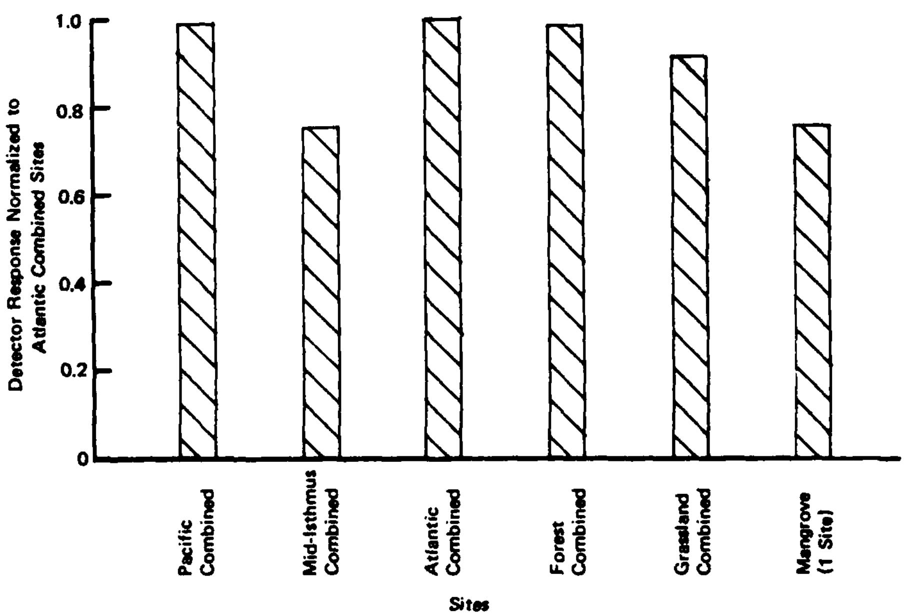


Figure IV-4. Average Total Volatile Hydrocarbon Concentration for Panama Sites Over a 24-Hour Period.

The solid adsorbent air sampling technique for concentration of volatile organic compounds proved satisfactory for tropic use.

Hydrocarbon compounds accumulated naturally on presumably biologically inert substrates and provided a medium which supported active microbial growth in the field. Approximately 20 percent of the condensed material consisted of two compounds having molecular weights of 198 and 208 atomic mass units. The lighter compound was an aliphatic ester found in Gynerium sagittatum (Savanna grass). The active fungal growth on the glass sampling plate (figure IV-5) shows that microorganisms can live on formerly biologically inert substrates after the substrates are exposed to the tropic environment.

Glass sampling plates proved successful for collecting natural accumulations of ambient organic compounds. The method has direct application to tropic testing because it provides a procedure to sample ambient chemical accumulations on items undergoing tropic tests.

Organic compounds are transported from the surrounding vegetation to the sampling plates, as evidenced by their identified presence from both sources. The fact that the condensed materials do not

Figure IV-5. Fungal Growth on Glass Sampler After 8-Month Exposure--Coco Solo Grassland Site (320X).

coincide with those collected by air sampling indicated that the mechanism of transport was not through volatile compounds.

Condensed hydrocarbon compounds were shown to serve as a nutrient medium for the growth of acid-producing and other destructive fungi. Airborne hydrocarbon compounds when deposited on exposed test items may lead to the biodeterioration of items that, by themselves, could not act as a sole carbon source for microorganisms. Thus, the study supports the contention that biodeterioration of normally biologically inert substrates can occur in the tropics.

The National Center for Atmospheric Research and USATTC conducted basic measurements of tropic air chemistry in the Canal Zone (Lodge, et al., 1973). They revealed low levels of ammonia and sulfur dioxide exist in Canal Zone tropic forests. These measurements later had direct input into the personnel detection SNIFFER system developed by the US Army Limited Warfare Laboratory, US Army Edgewood Arsenal, and the General Electric Corporation. The ammonia and sulfur concentrations were sufficient to mask personnel signatures for one of the candidate sensor systems. US Army Research Office-Durham (Alpert, 1974) determined that the availability of this information saved 18 months in developmental time on the airborne devices that were later used successfully in Vietnam.

D. TROPIC TEST SITE SEVERITY--ACCELERATED TESTS

Study of Six Materials at 16 Sites

Sprouse, et al. (1974) and Portig, et al. (1974) reported results of materials exposures in the Canal Zone. The objectives of the investigation were to: (a) determine whether weathering tests could be speeded up by identifying the most severe sites, (b) determine deterioration rates and patterns of six basic materials, and (c) determine the effects of tropic wet and dry seasons on deterioration.

The investigation used nine experimental field test sites, seven established sites having past histories of use for tropic testing, and one air-conditioned control site. The test sites consisted of open, forested, sheltered and coastal sites located throughout the Canal Zone on the Pacific coast, Atlantic coast and approximately at Mid-Isthmus. Six basic materials representing three general material classes--textiles, metals and rubber--were used as indicators of site severity. These basic materials were cotton, polyvinyl chloride, nylon, latex rubber, butyl rubber and mild steel. Materials were exposed at the tropic test sites for 1 to 48 weeks during four seasonal exposure phases with tensile strength, corrosion weight loss, and microbial coverage used as experimental measurements of site severity. Plots of tensile strength versus exposure time are presented in Section VI (figures VI-18 through VI-22). Details of the results obtained are discussed in the following paragraphs.

A single tropic exposure site cannot be characterized as generally severe in deteriorative properties. The degree of severity is dependent on the material being exposed. For example, a site that is severely degrading for cotton may be benign for mild steel.

The Atlantic and Pacific sides of the Isthmus provided exposure modes and sites equally severe on a representative cross section of types of materials, except for steel. Therefore, future site selection for exposure tests need not be based on an assumed relationship between the higher rainfall of the Atlantic side and deterioration severity.

It is possible to increase the severity of natural tropic exposure tests by careful selection of sites. This conclusion is based on reliable statistical differences in deterioration rates that exist among environmental exposure modes in geographic proximity.

An unexpected result of this study was that the most severe test site for steel was the mangrove swamp. Deterioration at the mangrove site was accelerated by at least a factor of two over the next most severe site at Galeta coastal.

Clusters of sites considered generally homogeneous in deterioration for steel, based on corrosion weight loss (Cluster I is most severe and Cluster V is least severe):

<u>Clusters</u>

I	Mangrove	V	F-Coco Solo
II	C-Galeta		S-Fort Gulick
III	C-Flamenco		S-Coco Solo
	O-Fort Gulick		S-Chiva Chiva
IV	F-Fort Sherman		F-Gamboa
	O-Fort Sherman		F-Fort Clayton
	O-Coco Solo		
	O-Gun Hill		
	O-Gamboa		
	O-Chiva Chiva		

Clusters of sites considered generally homogeneous in deterioration rates for cotton based on tensile strength loss (Cluster I is most severe and Cluster IV is least severe):

<u>Clusters</u>

I	F-Fort Sherman		IV	S-Fort Gulick
II	F-Gamboa			F-Coco Solo
	C-Flamenco			S-Chiva Chiva
III	C-Galeta			Mangrove
	O-Fort Gulick	O-Fort Sherman		
	F-Fort Clayton			
	O-Chiva Chiva			
	O-Gamboa			
	O-Coco Solo			
	S-Coco Solo			

Clusters of sites considered generally homogeneous in deterioration rates for nylon based on tensile strength loss (Cluster I is most severe and Cluster V is least severe):

Clusters

I C-Flamenco
C-Galeta
O-Fort Gulick
O-Fort Sherman
O-Coco Solo
O-Chiva Chiva
O-Gamboa
II S-Chiva Chiva
S-Fort Gulick
III Mangrove
IV S-Coco Solo
F-Gamboa
V F-Fort Clayton
F-Coco Solo
F-Fort Sherman

Clusters of sites considered generally homogeneous in deterioration rates for polyvinyl chloride based on tensile strength loss (Cluster I is most severe and Cluster IV is least severe):

Clusters

I C-Flamenco
II O-Fort Sherman
O-Chiva Chiva
O-Fort Gulick
III O-Gamboa
O-Coco Solo
C-Galeta
IV F-Fort Clayton
Mangrove
S-Fort Gulick
S-Chiva Chiva
F-Fort Sherman
F-Coco Solo
F-Gamboa
S-Coco Solo

Clusters of sites considered generally homogeneous in deterioration rates for latex based on tensile strength loss (Cluster I is most severe and Cluster VII is least severe):

Clusters

I O-Chiva Chiva
O-Coco Solo
O-Fort Sherman
O-Gun Hill
C-Galeta
O-Gamboa
C-Flamenco
O-Fort Gulick
II Mangrove
S-Fort Gulick
III S-Chiva Chiva
IV F-Fort Clayton
S-Coco Solo
V F-Gamboa
VI F-Coco Solo
VII F-Fort Sherman

LEGEND: C-Coastal site, O-Open site, S-Sheltered site, and F-Forested site.

Relative differences in site severity were not isolated for butyl rubber during this investigation. Exposure periods were not of sufficient length for environmental effects to produce deterioration as measured by material tensile strengths.

Corrosion weight loss and tensile strength are highly related indices of site severity on steel. Corrosion weight loss and tensile strength could be substituted for each other as measures of site severity on steel in certain cases.

Follow-up Study of Steel at Mangrove Sites

Because of the high rate of steel deterioration at the Coco Solo mangrove exposure site, and because only one mangrove site was used in the initial investigation, Johnson and Downs (1975) reported results of exposing an additional 1440 steel samples at eight (seven mangrove and one coastal) sites throughout the Canal Zone during the wet and dry seasons. The objective of this follow-up investigation was to determine if mangrove swamps were generally deteriorative of metals or if the Coco Solo site was unique. A total of 90 samples were exposed at each exposure site during each season. At weekly intervals, six samples were retrieved from each site and tested for tensile strength. This process continued until the last six samples were retrieved after 15 weeks of exposure. Samples of water run-off from the mangrove trees were also collected on a weekly basis and analyzed for total ionic strength (conductivity in Mho/cm), pH, and water soluble chloride concentration. Species of mangrove trees were classified at each mangrove site. The degradation rates during both seasons are shown in table IV-5. (Coco Solo Mangrove site "A" was the original site used and described in the preceding study.)

The major conclusions of the investigation were as follows:

The tensile strength losses ranged from 3.2×10^{-4} MPa/week at the Kobbe mangrove site during the dry season, to 8.2×10^{-3} MPa/week at the Coco Solo Mangrove site A during the wet season. Thus, mangrove swamps are not uniformly destructive to metal; the original Coco Solo site is uniquely severe.

The wet season exhibited higher corrosion rates than the dry season. The high degradation rate in the wet season is caused by a higher concentration of electrolytes in the rainwater run-off. The majority of the corrosion products are washed away by heavy rainfall, thereby exposing a new layer of steel that undergoes further corrosion. Conversely, a semipassivity on the surface of the samples in the dry season is developed since the water soluble corrosion products are not washed away.

The high conductivity of the water run-off is well correlated to the tensile strength loss. This high conductivity is caused primarily by water soluble salts found in the water run-off samples. These salts form on the leaves and branches of the mangrove trees by exudation and from saltfall onto the canopy.

Mangrove swamps are not universally severe to steel and must therefore be selected carefully in planning tropic exposure tests.

Table IV-5. Wet and Dry Season Degradation Rates (MPa/week change in tensile strength)

Site	Point Estimate	95-Percent Lower Confidence Limit	95-Percent Upper Confidence Limit
Wet Season	(average)		
Kobbe Mangrove (P)	1.2×10^{-3}	1.6×10^{-3}	8.8×10^{-4}
Fort Sherman Mangrove A (A)	2.1×10^{-3}	2.6×10^{-3}	1.7×10^{-3}
Rodman Mangrove (P)	2.6×10^{-3}	3.2×10^{-3}	2.0×10^{-3}
Fort Sherman Mangrove B (A)	2.6×10^{-3}	3.1×10^{-3}	2.0×10^{-3}
Coco Solo Mangrove B (A)	2.8×10^{-3}	3.1×10^{-3}	2.4×10^{-3}
Breakwater (Comparison) (A)	5.8×10^{-3}	6.1×10^{-3}	5.5×10^{-3}
Galeta Point Mangrove (A)	5.8×10^{-3}	6.1×10^{-3}	5.5×10^{-3}
Coco Solo Mangrove A (A)	8.2×10^{-3}	9.0×10^{-3}	7.5×10^{-3}
Dry Season			
Kobbe Mangrove (P)	3.2×10^{-4}	5.3×10^{-4}	1.1×10^{-4}
Galeta Point Mangrove (A)	4.4×10^{-4}	6.4×10^{-4}	2.3×10^{-4}
Rodman Mangrove (P)	6.5×10^{-4}	9.4×10^{-4}	3.6×10^{-4}
Fort Sherman Mangrove A (A)	6.8×10^{-4}	8.3×10^{-4}	5.2×10^{-4}
Coco Solo Mangrove B (A)	8.3×10^{-4}	1.0×10^{-3}	6.5×10^{-4}
Fort Sherman Mangrove B (A)	9.5×10^{-4}	1.1×10^{-3}	8.0×10^{-4}
Coco Solo Mangrove A (A)	5.2×10^{-3}	5.7×10^{-3}	4.6×10^{-3}
Breakwater (Comparison) (A)	1.1×10^{-2}	1.2×10^{-2}	1.1×10^{-2}

LEGEND: (A)-Atlantic site. (P)-Pacific site.

Exposure/Performance Tests of Selected Materiel Items

Downs and Gorak (1979) reported results of exposing materiel items at a number of exposure sites and in different exposure modes in the Canal Zone and of performance testing these items at regular intervals. The objectives of the study were to learn how and when to measure test item performance and to relate performance measures to visual evidence of deterioration.

Bases for selection of items included measurable performance characteristics, hypothesized susceptibility to tropic deterioration, and common Army usage. The following were included: 3.5-inch rocket cases, tactical radios, automotive roller bearings, POL products, plastic films, timers, batteries, windshield wiper motors and blades, and automotive V-belts.

The exposure modes for these items were shed storage at open sites, shed storage under forest canopy, pallet and tarpaulin storage at open sites and pallet and tarpaulin storage under the forest canopy (table IV-6). The exposure modes were selected to be representative of long-term combat storage conditions.

Table IV-6. Sites Representing Each Exposure Mode

Exposure Mode	Site
Shed Storage, open sites	Coco Solo Open Fort Gulick Open Fort Clayton General Purpose Test Area
Shed Storage, forest sites	Fort Sherman Forest (Skunk Hollow) Gamboa Forest
Pallet and tarpaulin, open site	Fort Sherman Open
Pallet and tarpaulin, forest site	Coco Solo Mangrove Gamboa Forest
Dark, air-conditioned laboratory	Corozal, Bldg 19

Significant deterioration in performance was most apparent for items exposed in the pallet- and tarpaulin-forest exposure modes. Significant deterioration was found as early as 2 months after exposure for some items; however, most items required at least 6 months for significant deterioration to be discernable.

Corrosion was the primary deteriorative agent for material in all exposure modes studied in the investigation. Corrosion was most rapid

and severe in the pallet- and tarpaulin-forest exposure modes, as exemplified by extensive corrosion on automotive roller bearings found unserviceable after 2 months of exposure in spite of being wrapped in corrosion-inhibiting paper.

There was no evidence that microbial growth or insect infestation were related directly to material or performance deterioration of the items exposed to the humid tropic environment. However, it was evident that they indirectly contributed to the corrosive process by causing the deterioration or, in some cases, the total destruction of the boxes in which the test items were packaged.

Visual evidence of exterior item deterioration from tropic exposure does not assure that item performance has degraded nor does the lack of exterior deterioration assure the absence of performance degradation.

SECTION V. TROPIC DEGRADATION OF MATERIALS

A. INTRODUCTION

All materials undergo environmental degradation effects and the degree and kinds of degradation in the humid tropics depend primarily on response of the exposed item to factors such as high temperature and humidity, intense solar radiation, intense biological activity and opportunity for chemical reactions based on atmospheric constituents and contaminants. It is generally accepted that damage due to tropic exposure occurs more rapidly and with greater severity than in temperate, desert, or arctic sites because of the variety of degrading mechanisms acting simultaneously.

This section summarizes data on natural weathering resistance of plastics and rubbers, protective coatings and wood, and the corrosion resistance of metals. Information on synthetic polymers has been stressed because of their increasing use in Army materiel. Much early work on natural polymers has not been included because of their decreasing role as basic materials in critical applications.

B. PLASTICS AND RUBBERS

Deteriorative chemical changes in polymers depend on the chemical design of the polymer. Polymers are generally classified into two large groups--the chain-like polymers comprising the thermoplastics and rubber, and the highly branched networks comprising the thermosetting plastics. Organic compounds in general are susceptible to chemical reactions with water vapor, ozone and oxygen. In the presence of light, degradative chemical reactions accelerate. Plastics give evidence of degradation by exhibiting crazing, cracking, embrittlement, granulation, hardening and discoloration.

Rain Erosion Tests

Wahl (1968) reported on comparative rain erosion tests of various types of polymeric materials. The tests were conducted on the whirling arm apparatus which simulates high speed flights through rain under controlled conditions. Flat and airfoil-shaped specimens, fabricated from plastics or metals with and without coatings, were mounted on the leading edge of the whirling arm and evaluated for erosion resistance at 500 miles-per-hour (mph) in 1-inch per hour rainfall. It was observed that the erosion resistance of standard neoprene coatings was increased about threefold when the neoprene was treated with an antiozonant solution.

Specimens were exposed at Florida, Panama and Wisconsin sites to determine the effects of weathering on rain erosion resistance. Results of the rain erosion tests (table V-1) indicated that the erosion resistance of standard neoprene coatings and an experimental white

radome coating was reduced substantially at each location after 1 year of outdoor exposure. The rain erosion resistance of thermo-plastic polycarbonate laminates was better than polyester or epoxy laminates.

Table V-1. Time of Destruction of Neoprene-Coated Airfoil Specimens after Outdoor Exposure*

Coating**	Control Specimens (minutes)	Florida 3 mo	Florida 6 mo	Florida 1 yr	Panama 3 mo	Panama 6 mo	Panama 1 yr	Wisconsin 3 mo	Wisconsin 6 mo	Wisconsin 1 yr
		(minutes)			(minutes)			(minutes)		
Goodyear 23-56	40	30	36	35	60	32	15	30	48	38
Goodyear 23-56 (epoxy)	55	40	50	45	50	45	20	45	42	30
R14L-27-296 antistatic	35	30	40	55	25	75	25	30	45	75
Gates N-79	30	25	21	20	30	35	28	40	33	25
Gates KV-9431 White	30	30	27	20	35	15	5	25	30	25

* Specimen speed 500 miles-per-hour, rainfall rate 1 inch-per-hour
**All coatings were applied on polyester laminate airfoils except Goodyear 23-56 (epoxy) which was an expoxy laminate.

Weathering Tests

Items left exposed to an environment are degraded by a number of factors in that environment. The ultraviolet portion of the solar spectrum is generally considered to be the most important factor in degradation of exposed materials. Amounts of radiation received are dependent on such factors as latitude, time of day, season, altitude above sea level, and local atmospheric conditions (clouds, fog, dust, etc.). Terrain features affect temperatures which are time as well as altitude dependent. As a general rule, chemical reactions proceed at a doubled rate for each 10°C rise in temperature. Humidity and precipitation conditions are, of course, to be considered. While wind is not in itself degradative, sand, dust, chemical impurities and airborne fungi are carried and deposited on the exposed item. Wind influences drying rates and can remove degrading products which may be either protective or catalytic. One of the most damaging chemicals is sea salt.

Williams (1974) conducted a study to determine the resistance of rubber-to-metal vulcanized bonds to long-term storage and to duplicate long-term environmental effects with an accelerated laboratory test. Four elastomers commonly used in various types of weapon components

were selected: butadiene/styrene, ethylene propylene terpolymer, neoprene, and butadiene/acrylonitrile. Vulcanized bonded specimens were prepared for outdoor exposure in Panama and Rock Island, Illinois, for 3 years. Samples were tested at 6-month intervals.

Butadiene/acrylonitrile and ethylene propylene terpolymer showed a severe loss in bond strength in both the environmental exposures and the accelerated laboratory tests. Butadiene/styrene and neoprene showed no significant loss in bond strength in either type of testing. It was concluded that a degree of correlation was established between the results of long-term outdoor tests and short-term accelerated tests, but that the laboratory test periods (up to 56 days) were too long for an accelerated test.

Bergstrom (1974) exposed various vulcanizates to weathering in the arctic, temperate and tropic climates of Alaska, Rock Island and the Canal Zone (Fort Sherman). After a 10-year period it was found that the Panama samples showed the most change in elongation and tensile strength. The most severe aging occurred in the polyester urethane samples exposed in Panama. The cis-polybutadiene specimens were severely aged at all three exposure sites. Neoprene, which averaged a 24 percent change in elongation at the arctic and temperate exposure sites, showed a 66 percent change in elongation at the Canal Zone site.

A 10-year tropic exposure test of compounded synthetic rubber was conducted by Teitell (1974). The purpose of the work was to compare effects of five different modes of tropic exposures on rubber materials. Test conditions included an open exposure, soil burial, sea immersion and two rain forest exposures: one under the canopy and one within a hut. Control laboratory samples were maintained in the dark. Twenty rubber formulations of six elastomers were used in the study. The principal additives were to provide color, microbiological resistance and block degrading effects of ultraviolet light. It was found that two hydrocarbon rubbers, copolymers of ethylene, propylene and hexadiene, withstood the 10-year tropic exposure, with the exception of those specimens exposed at the open site. Direct exposure to solar radiation had a pronounced degrading effect on white rubber. Neoprene with 15 percent red lead had good microbiological protection against soil burial. Hexafluoropropylene and vinylidene fluoride were the most resistant rubbers at all tropic exposure sites, except in the sea immersion test where marine organisms fouled the rubber slab. Polyurethane rubber was markedly affected by ultraviolet radiation because carbon black was not present to act as an inhibitor. Natural rubber deteriorated rapidly in all exposures except those samples placed in the hut in the rain forest.

Phenolics (Rugger, 1968) are of two types--cellulosic and mineral, and are mostly used in a reinforced state. Commonly used fillers are woodflour, cotton flock, cotton fabric asbestos, glass and synthetic fibers. Exposure test results in terms of tensile strength changes for various environments in open exposure are illustrated in figures V-1, V-2 and V-3.

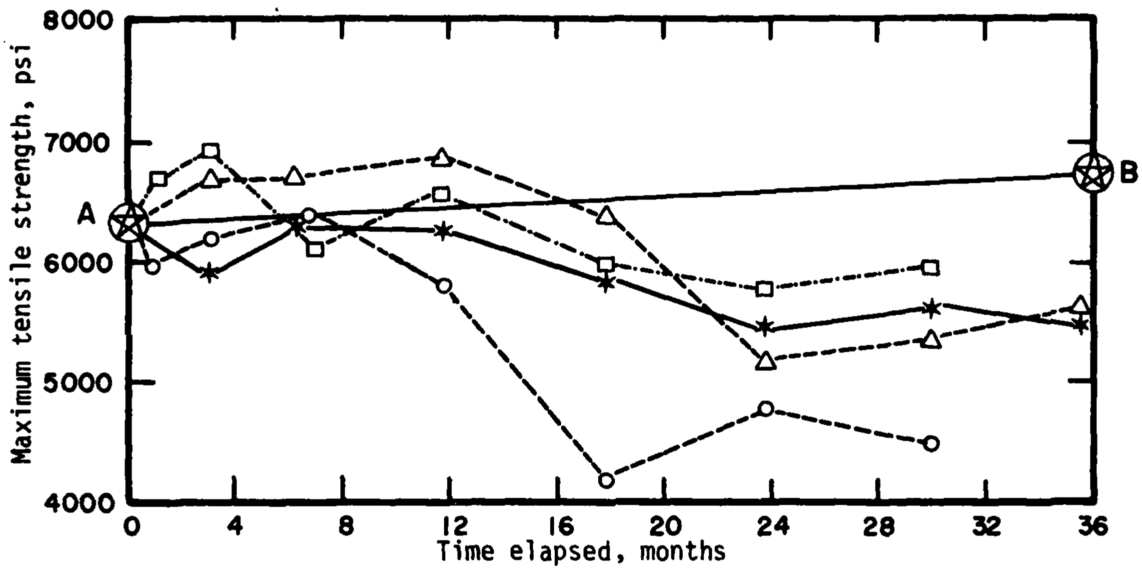


Figure V-1. Molded Woodflour-Filled 2-Step Phenolic with Black Dye. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

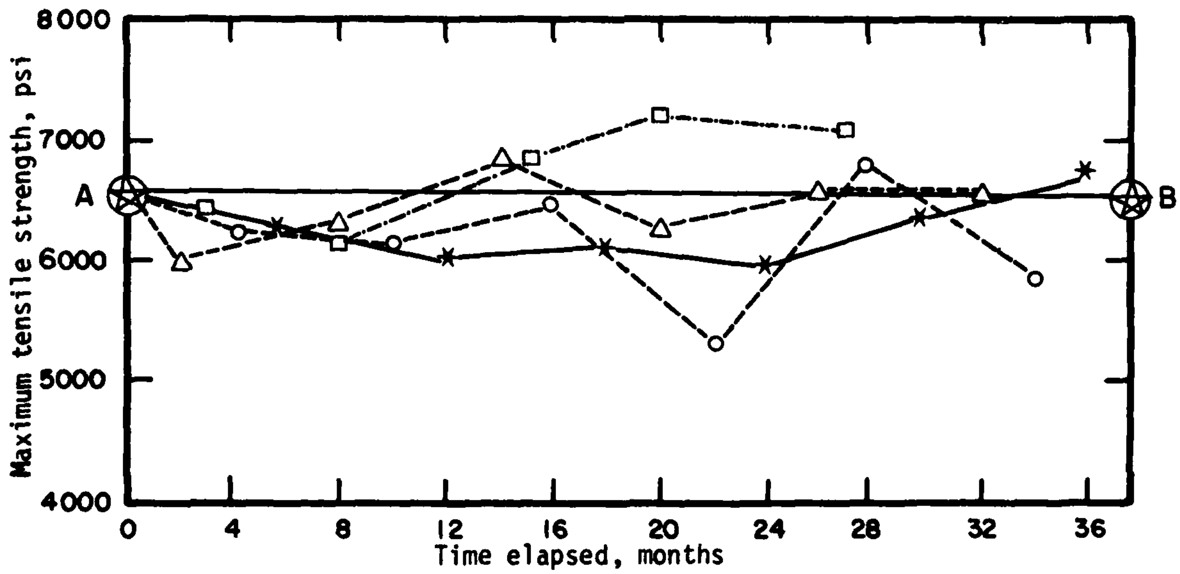


Figure V-2. Molded Polyimide Flock-Filled Phenol Formaldehyde. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands ○ Panama. Initial Control, A; Final Control, B.

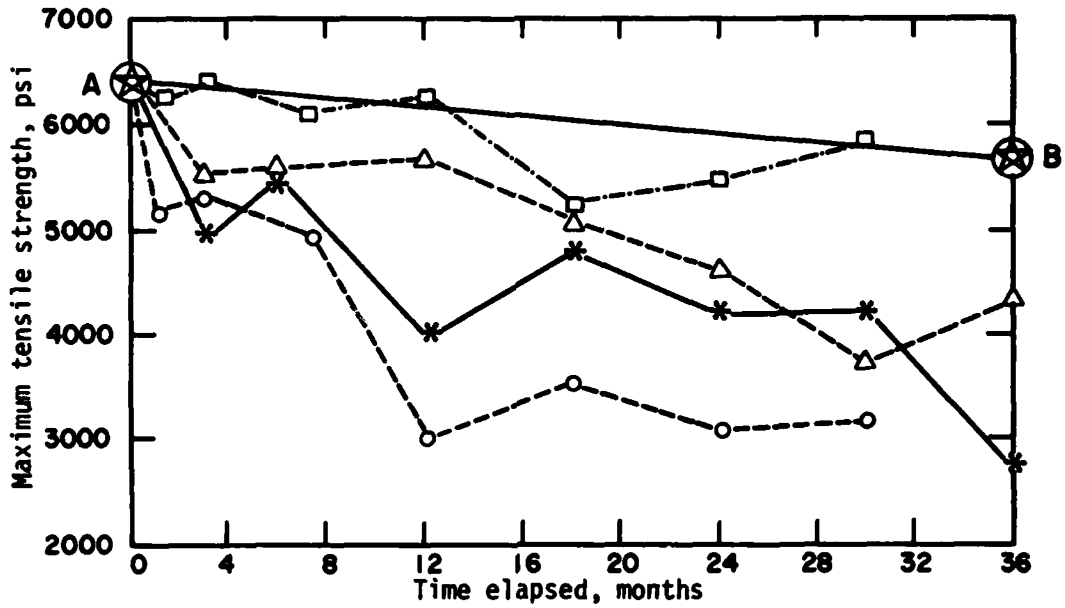


Figure V-3. Molded Woodflour-Filled 2-Step Phenolic with Natural Color. Exposure at: ✱Picatinny, △Fort Churchill, □White Sands, ○Panama. Initial Control, A; Final Control, B.

Epoxies are often used as resinous binders for reinforcements. Wegman et al., (1968) reported work on 17 different adhesive formulations used to bond 2024T-3 aluminum alloy panels to form lap joints. The bonded panels, in an unstressed condition, were exposed at Picatinny Arsenal, Yuma, Arizona and Panama. Tensile shear strengths were measured on each adhesive lap joint after a 3-year exposure at each test site and also after a temperature-humidity cycling chamber test. It was found that the adhesive joints which were stored in the laboratory at Picatinny or weathered in a hot dry climate (Yuma) retained most of their original strength. Some of the adhesive-bonded joints were affected adversely by exposure in Panama; noted was failure or weakening caused by exfoliation or crevice corrosion of the aluminum adherent in the bonded area. How the adhesive had accelerated the corrosion is unknown. Based on a 3-year exposure at all weathering sites, a glass-cloth-supported, aluminum-filled, epoxy-phenolic film adhesive and an unsupported nitrile-phenolic thermosetting film adhesive were considered the best overall of the adhesive systems tested.

Sacher (1976) reported the results of a 2-year study of weathering degradation of an epoxy-fiber-glass laminate composite system. World-wide test sites were employed. Data on short beam shear, tensile and flexural strengths for the various test sites are presented in tables V-2, V-3, and V-4.

Table V-2. Comparison of Short-Beam Shear Strengths of Laminate Composites

(Initial Controls 5.5 x 10^3 psi)

Test Sites	Environment	Weathered 6 months		Weathered 12 months		Weathered 18 months		Weathered 24 months	
		% Change	CV*	% Change	CV*	% Change	CV*	% Change	CV*
Canal Zone									
Atlantic Open	Humid Tropic	3.1	3.3	- 4.4	9.9	- 0.4	3.4	-15.3	5.4
Pacific Open	Humid Tropic	3.2	3.7	- 4.5	16.5	- 4.9	3.9	- 7.4	4.7
Atlantic Coastal	Humid Tropic	1.5	4.6	2.2	5.0	- 4.7	9.2	-12.5	6.4
Atlantic Jungle	Humid Tropic	7.6	2.3	- 4.4	6.9	- 6.0	3.8	- 6.7	3.8
Puerto Rico	Humid Tropic	--	--	- 4.6	7.1	- 4.2	4.3	- 9.0	9.0
Arizona	Desert	--	--	- 2.2	5.3	0	8.8**	0.2	9.2
Massachusetts	Temperate	-14.7	10.2	- 9.1	3.2	- 3.2	3.6	-10.0	4.3
Australia									
Innisfail	Humid Tropic	7.1	13.8	- 7.1	5.0	-18.2	11.9	-26.9	10.3
Cloncurry	Dry Tropic	- 1.8	4.8	- 2.5	6.4	-14.2	10.3	-18.0	12.6
Maribyrnong	Temperate	2.5	6.8	-11.4	8.2	-14.2	9.2	-18.7	11.0
Germany	Temperate	0.3	4.3	0.3	5.8	-12.4	7.0	-15.8	13.9

*CV: % Coefficient of Variation.
**21-Month Exposure.

Table V-3. Comparison of Tensile Strengths of Laminate Composites

(Initial Control 735 x 10^{-2} psi)

Test Sites	Weathered 6 months		Weathered 12 months		Weathered 18 months		Weathered 24 months	
	% Change	CV*	% Change	CV*	% Change	CV*	% Change	CV*
Open Site	-13.1	3.5	- 7.4	5.2	3.1	10.9	-15.5	7.9
Chiva Chiva	- 9.2	2.5	- 4.3	5.3	-14.6	8.0	-17.7	7.4
Breakwater	-14.2	2.6	-11.1	9.5	-15.5	7.4	-23.9	11.4
Rain Forest	-10.3	7.4	- 7.0	9.5	-15.5	8.9	-12.7	21.1
Caribbean	5.1	10.8	- 9.1	3.6	-16.8	18.9	-10.3	3.0
Yuma	- 5.9	7.8	- 4.2	0.1	- 2.4	5.5**	- 4.4	5.1
Maynard	- 0.3	7.5	-12.0	4.4	10.4	4.9	-11.0	13.1
Innisfail	-16.9	11.3	-14.8	4.4	- 9.1	5.1	15.2	7.9
Cloncurry	- 2.2	8.1	-11.2	13.8	- 5.4	5.0	-12.5	7.1
Maribyrnong	- 9.9	3.6	- 3.9	5.3	-11.2	4.3	-15.4	10.9
German	10.6	4.3	10.4	6.6	7.5	11.0	3.4	5.6
Soil-Buried							- 8.9	6.9

*CV: % Coefficient of variation
**21-Month Exposure

Table V-4. Comparison of Flexural Strengths of Laminate Composites

(Initial Control 144 x 10^3 psi)

Test Sites	Weathered 6 months		Weathered 12 months		Weathered 18 months		Weathered 24 months	
	% Change	CV*	% Change	CV*	% Change	CV*	% Change	CV*
Open Site	-20.3	10.5	-17.2	18.0	-10.9	3.7	-30.5	7.5
Chiva Chiva	-17.7	3.7	1.5	4.3	-11.7	3.9	-19.5	4.2
Breakwater	2.5	9.3	- 1.8	2.3	-15.1	6.7	-28.0	10.5
Rain Forest	-12.4	3.0	- 1.5	15.7	-22.2	9.1	-14.1	3.6
Caribbean	6.4	3.7	-14.0	1.5	-27.6	9.6	-25.6	9.0
Yuma	- 5.1	6.0	- 4.5	4.3	- 3.1	7.1**	- 5.3	7.7
Maynard	-15.2	2.7	- 4.3	14.6	- 7.4	6.4	-16.5	8.5
Innisfail	- 4.2	9.9	- 7.4	7.8	-25.4	30.5	-21.6	13.2
Cloncurry	4.9	4.9	5.4	5.7	0.9	3.9	- 7.6	4.9
Maribyrnong	8.9	6.4	5.9	3.8	0.3	7.1	-11.7	13.3
German	10.4	7.8	- 0.3	1.9	- 5.4	5.7	- 5.4	5.2
Soil-Buried							-20.7	4.6

*CV: % Coefficient of variation
**21-Month Exposure

After a 2-year exposure, the specimens showed deterioration effects in different ways. The most severe degradation took place in hot, humid sites such as the Fort Clayton General Purpose Test Area open site (Chiva Chiva) in the Canal Zone. There was 12 to 16 percent deterioration at the rain forest site in Panama. The least amount of degradation took place at the Yuma site where humidity is low. A large variability in results was attributed to the heterogeneous nature of samples caused by poor quality control in processing. The data, even with their variability, show that the laminate composite materials are most susceptible to weathering degradation under conditions of high humidity and solar radiation loads.

Melamines and ureas fall into the general category of amino resins. Rugger (1968) compiled data on exposure tests of various samples of these compounds (table V-5, and figures V-4 and V-5).

Weathering resistance of silicone laminates was also tested. Figure V-6 shows tensile strength data for these compounds.

While the term "thermosetting materials" can be applied to many different chemical types of compounds, each of which can be physically or chemically modified, the interest in the effects of weathering is largely confined to phenolics, polyesters, and epoxies. Thermoplastics, on the other hand, are more diverse chemically and interest in their weatherability extends fairly well across the spectrum of available materials. In addition, thermoplastics readily lend themselves to such techniques as blending, copolymerization, and block and graft polymerization. These techniques influence the ability of the material to withstand outdoor exposure.

The term "acrylics" technically refers to a large class of compounds, but ordinarily refers to the specific compound polymethyl methacrylate. Exposure test results (Rugger, 1968) changes are shown in figure V-7 for the various environments.

Cellulosic compounds often weather poorly when exposed to sunlight, but effective means of stabilization have been found. Data gathered on two polymers exposed in varying climates are shown in figures V-8, V-9, and V-10 (Rugger, 1968).

Blinne and Day (1964) of Picatinny Arsenal exposed samples of commercially available plastics in four contrasting environments: temperate (Picatinny Arsenal), tropical (Canal Zone), arctic (Canada and Alaska), and desert (White Sands). After 3 years of exposure, performance was summarized. It was reported that polypropylene showed a

Table V-5. Comparison of Flexural Strengths of Melamine Laminated Sheet Plastics

Exposure site	Exposure period (years)	Flexural strength (100 psi)
Shelf	0	355
Panama	1	320
	2	334
	2.5	279
New Mexico	1	335
	2	296
	2.5	278
New York	1	347
	2	331
	3	344
Canada	1	350
	2	322
	3	323
Alaska	1	351
	2	324
	3	308
New York	Shelf	308
	2	340
	3	335
	4	304
	5	239
	6	301
	7	297
	8	298
	9	320
	10	300

Note: Hardness. Rockwell hardness values were found to decrease after a 2.5- to 3-year exposure period at Panama, New Mexico, New York, Canada, and Alaska.

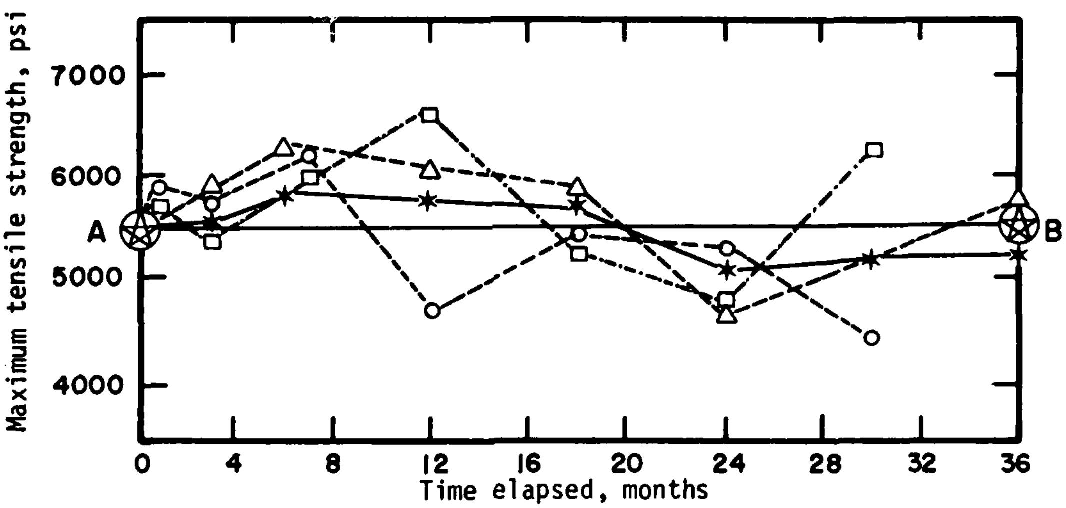


Figure V-4. Alpha Cellulose-Filled Melamine Formaldehyde. Exposure at: ✱Picatinny, △Fort Churchill, □White Sands, ○Panama. Initial Control, A; Final Control, B.

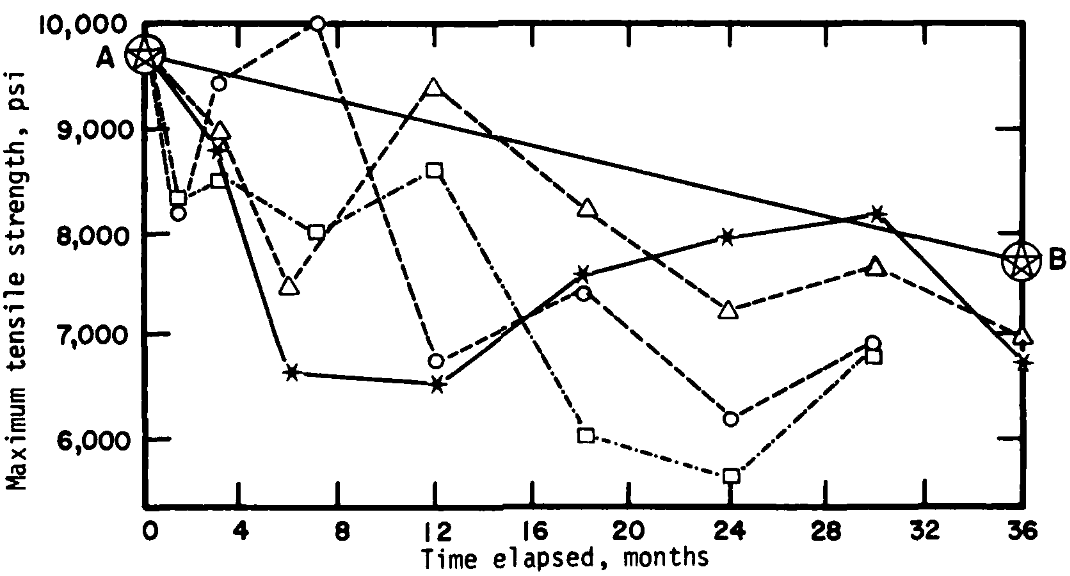


Figure V-5. Alpha Cellulose-Filled Urea Formaldehyde. Exposure at: ✱Picatinny, △Fort Churchill, □White Sands, ○Panama. Initial Control, A; Final Control, B.

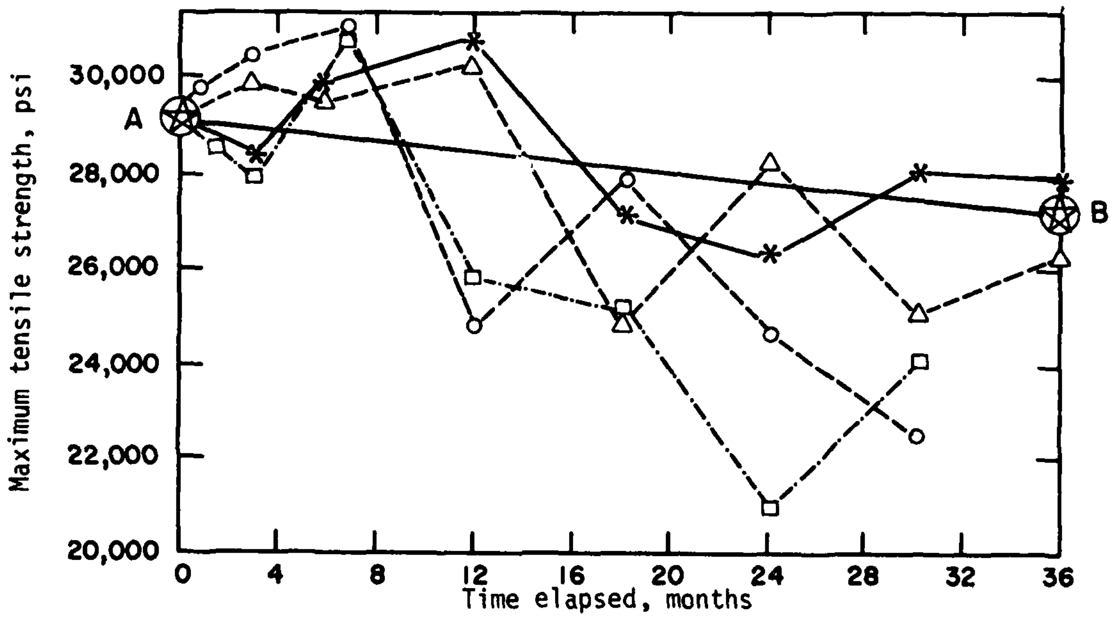


Figure V-6. Medium Weave, Glass Fabric, Silicone Laminate. Exposure at: *Picatinny, △Fort Churchill, □White Sands, ○Panama. Initial Control, A; Final Control, B.

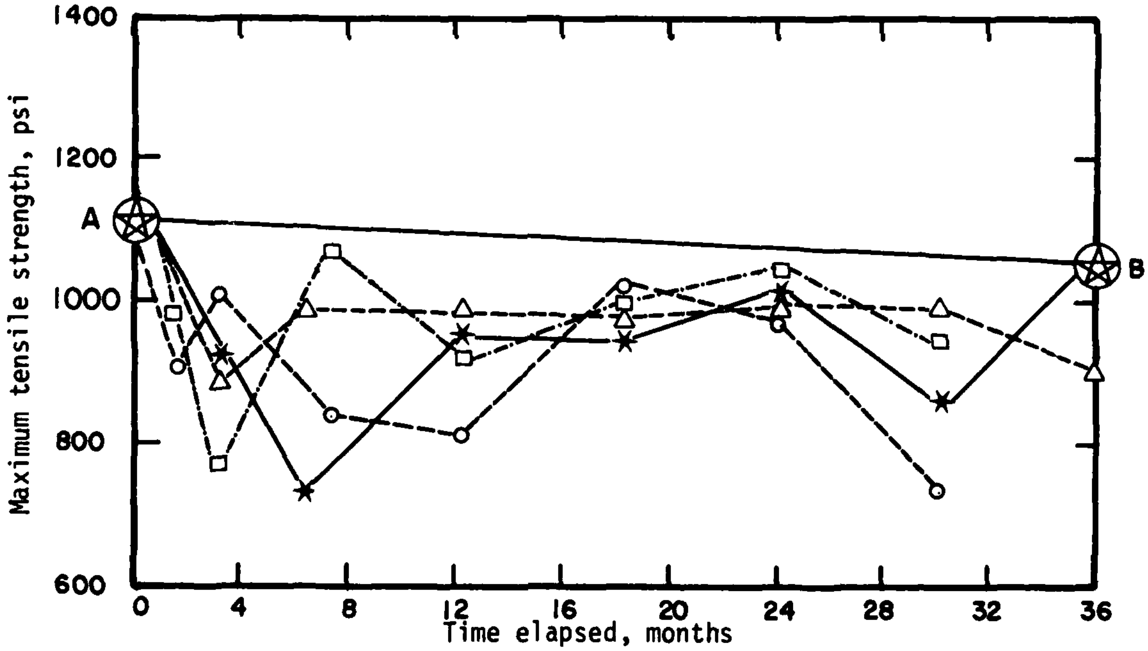


Figure VI-7. Cast Polymethyl Methacrylate. Exposure at: *Picatinny, △Fort Churchill, □White Sands, ○Panama. Initial Control, A; Final Control, B.

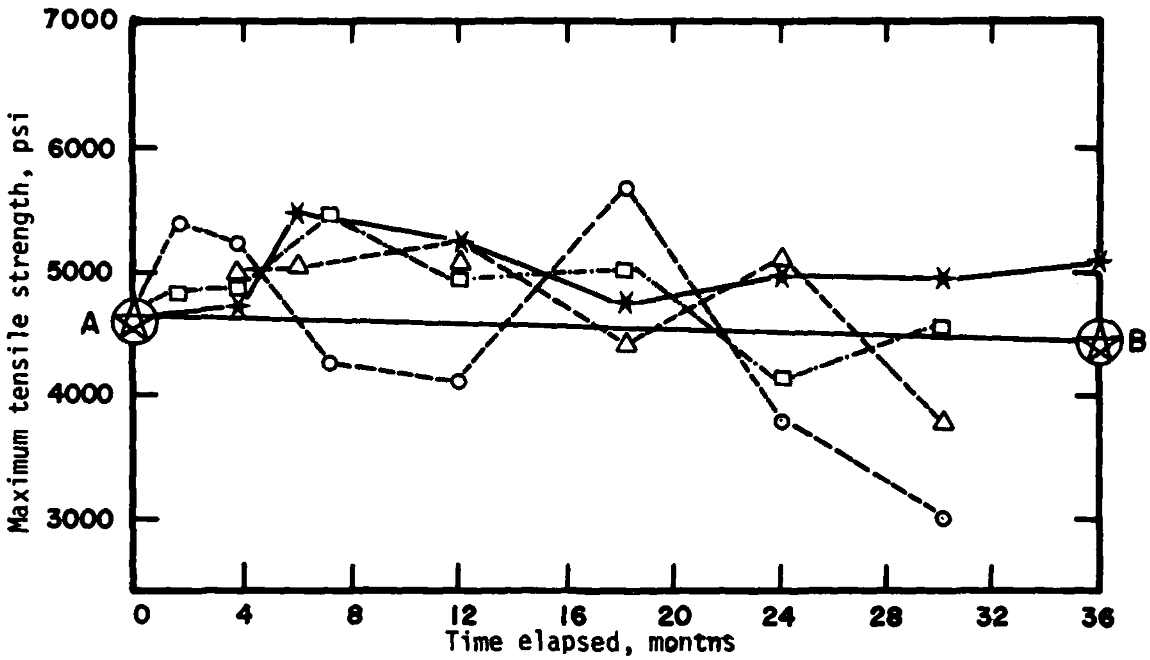


Figure V-8. High Acetal Cellulose Acetate (Hard Flow). Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

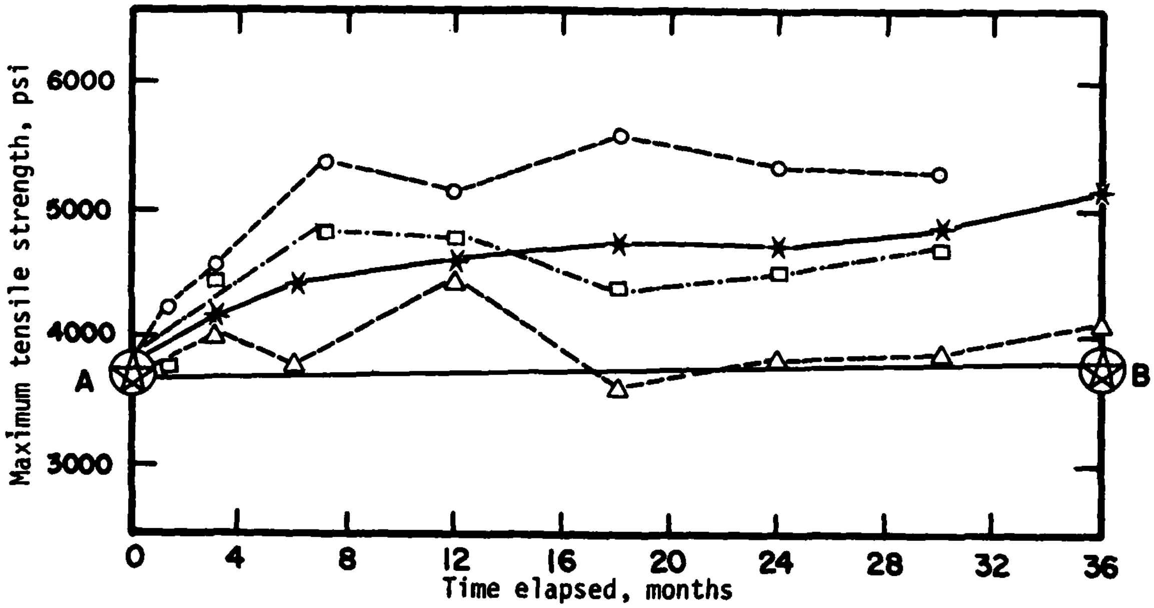


Figure V-9. High Acetal Cellulose Acetate (Medium Soft Flow). Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial control, A; Final Control, B.

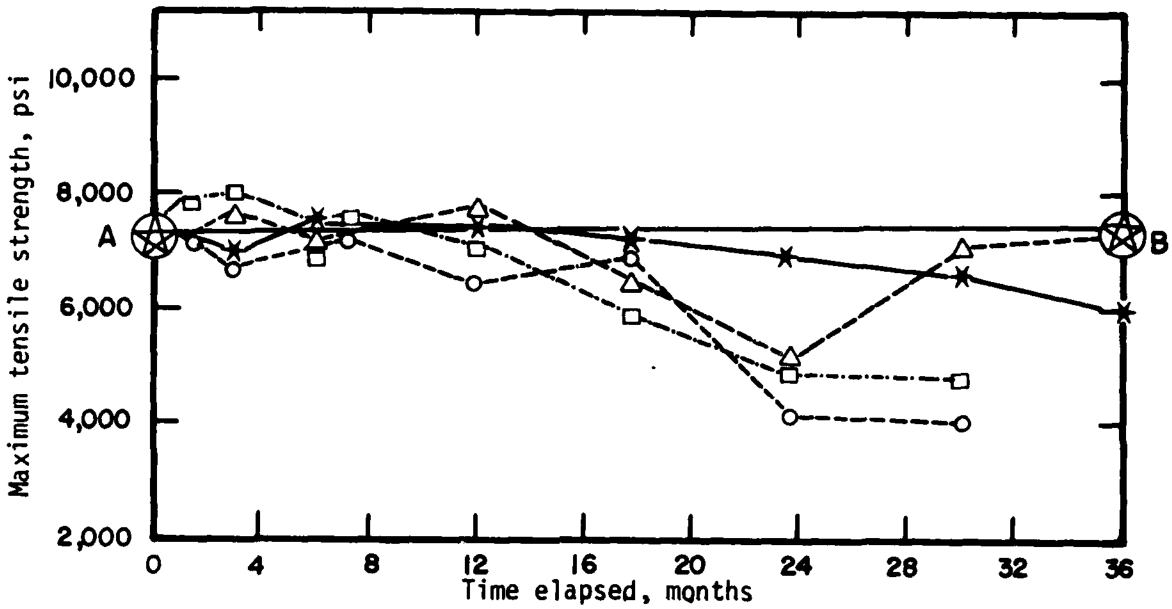


Figure V-10. Cellulose Acetate Butyrate (Hard Flow). Exposure at: ✱Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

decrease in elasticity and yield strength after outdoor exposure, particularly at Panama. Two other types of thermoplastics were also exposed. Polycarbonate resins became embrittled, the arctic exposure having the greatest effect, with Panama next. A black acetal was embrittled by a 3-year exposure at Picatinny and arctic sites, but was unaffected by 3 years in Panama. The white acetal samples were embrittled to a greater extent at all sites, but the Panama exposure had the greatest effect on this material.

Figure V-11 shows characteristic responses of polyethylene to high temperatures and ultraviolet radiation. Figure V-12 illustrates that carbon black and antioxidant additives increase weatherability (Rugger, 1968).

The incorporation of flourine into the polymer structure (fluorocarbons) seems to impart exceptional weathering resistance. Tetrafluoroethylene data (figure V-13) show that 15 years of exposure are not harmful even for a 3-mil thick film (Rugger, 1968).

Polystyrene and its copolymers are widely used; however, even with improvements such as addition of carbon black, such compounds weather poorly, as shown by figure V-14 (Rugger, 1968).

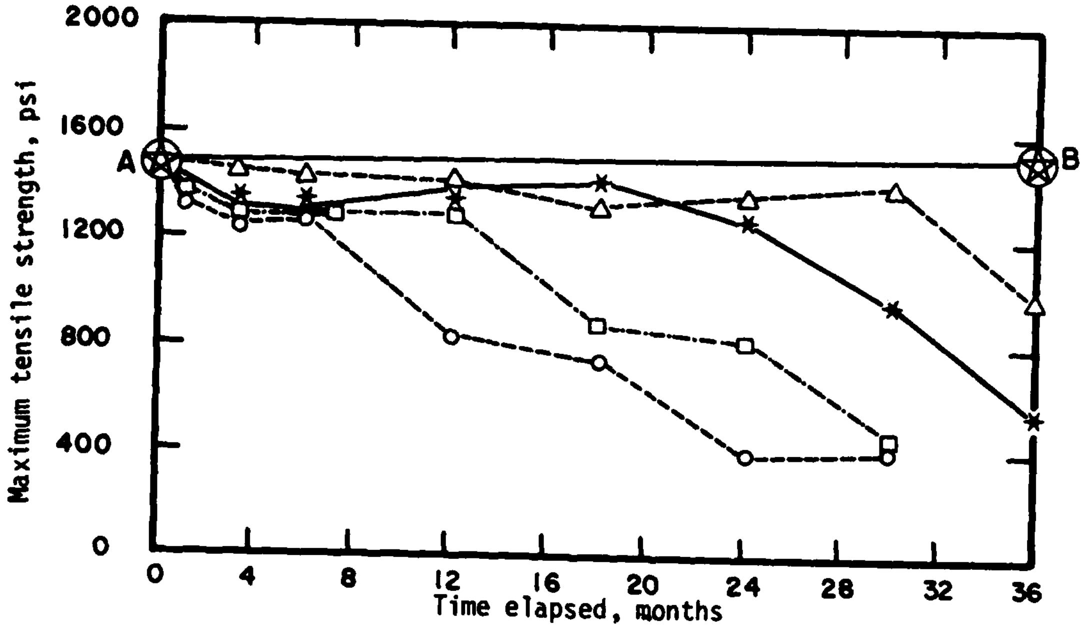


Figure V-11. Low Density Polyethylene. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

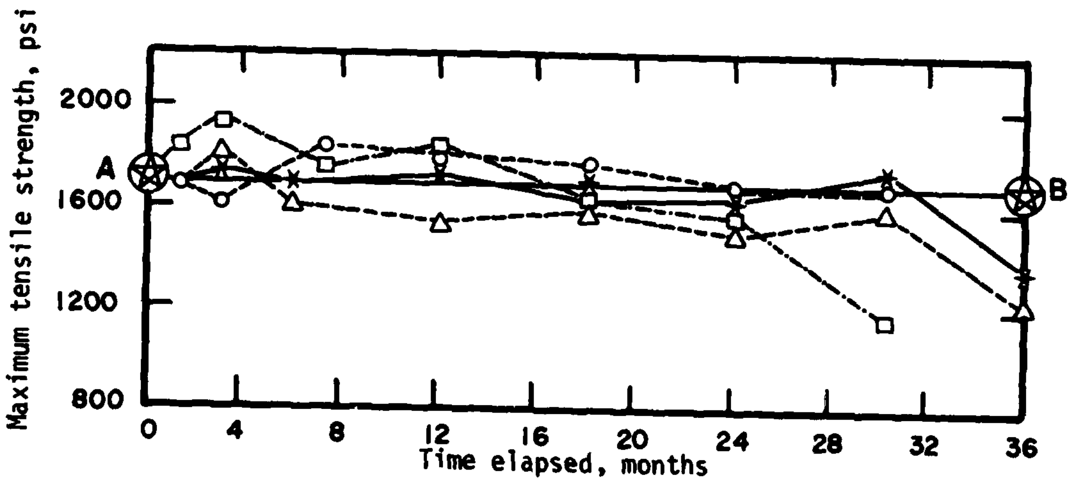


Figure V-12. Low Density Polyethylene with 1-Percent Carbon Black and 0.1 Percent Antioxidant Added. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

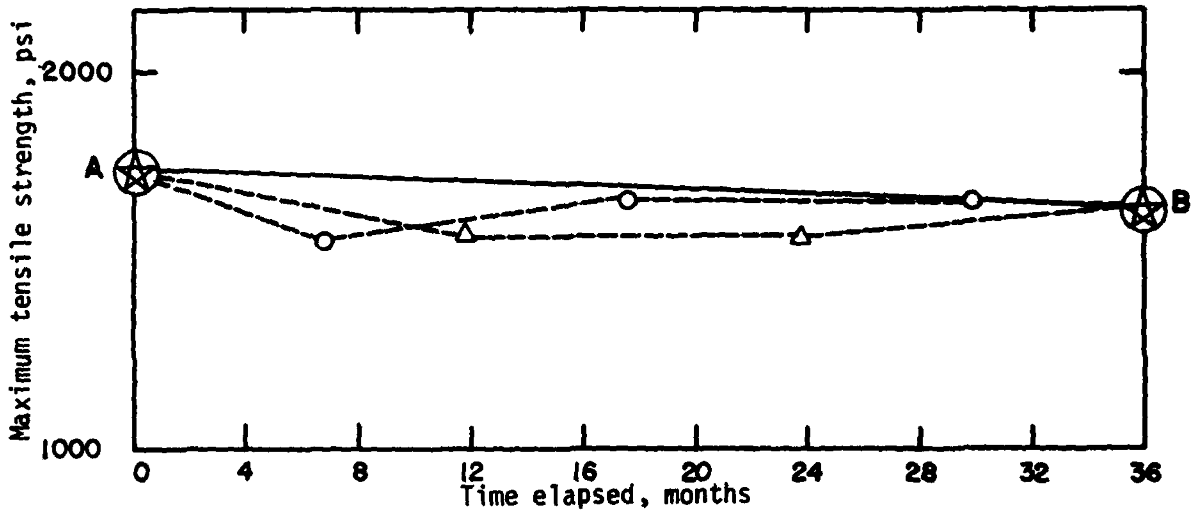


Figure V-13. Polytetrafluoroethylene. Exposure at: ○ Panama, △ Fort Churchill. Initial Control, A; Final Control, B.

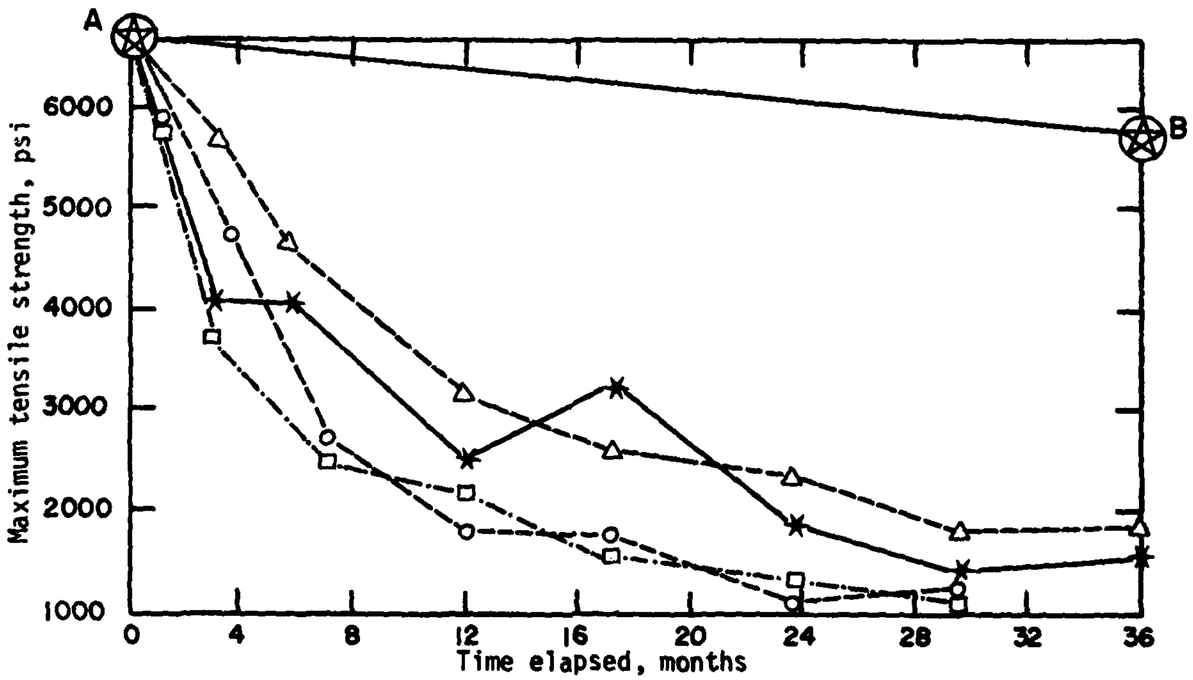


Figure V-14. General Purpose Polystyrene. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

Polyvinyl chlorides (PVC) are represented by many different formulations. While the basic polymer is relatively insensitive to weathering, the inclusion of additives may significantly alter this property. Figures V-15 and V-16 show some exposure results that illustrate the deleterious effects of plasticizers on weathering durability (Rugger, 1968).

Rauschert (1955) evaluated plastic articles in the Amazon region. He found that PVC films gave good performance except for warping and staining. Nonpigmented polyethylene film was inferior, showing less resistance to handling and damage and becoming brittle after 2 1/2 months of exposure to sunlight.

Blahnik and Lappala (1957) studied photodegradation in plastic films in Florida. A number of plastic films including PVC were tested by stretching them with "moderate" tension over the top of open drums containing wet sand. The drums faced south at 15 degrees in Florida, 1 mile from the ocean. In sunlight, moisture was constantly evaporated from the sand, maintaining a temperature of about 135°F. Tensile strengths of the test strips after 6 months of exposure indicated that the presence of moisture during weathering has a profound influence on results, and that data taken on dry films were irrelevant when use entailed moisture or contact with water against one side of the film.

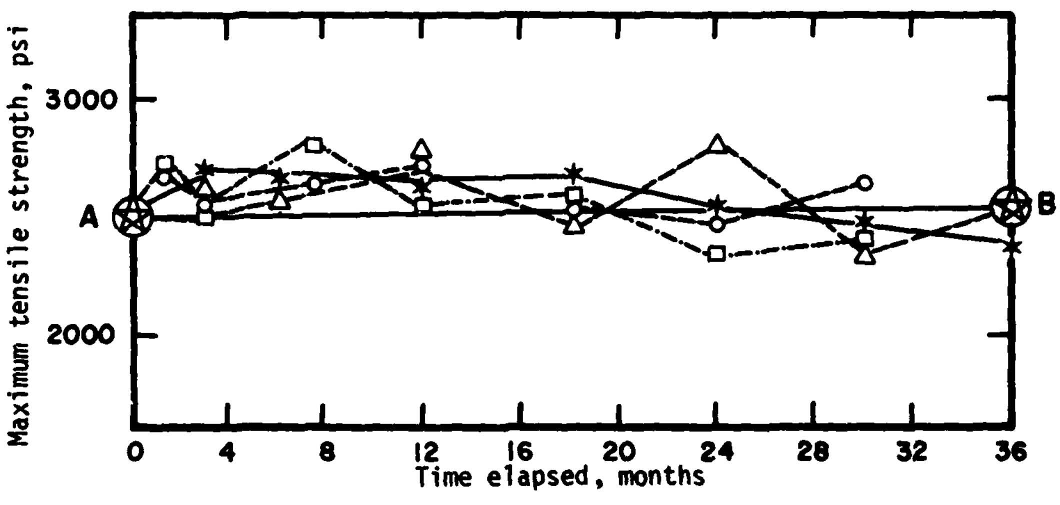


Figure V-15. General Purpose Polyvinyl Chloride with 1-Percent Plasticizer and 1-Percent Carbon Black. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

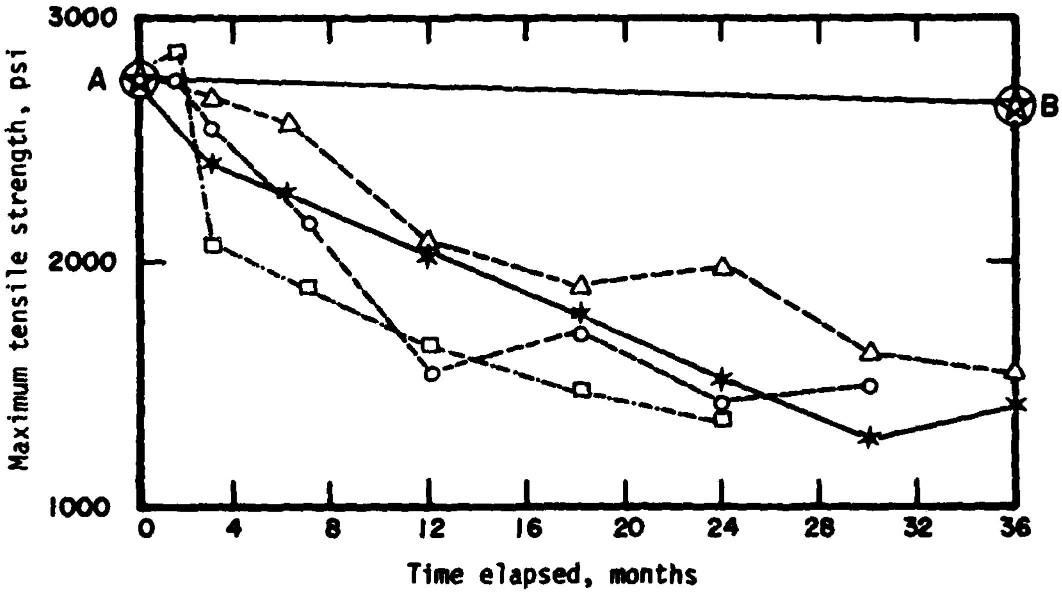


Figure V-16. General Purpose Polyvinyl Chloride with 33-Percent Plasticizer and 2-Percent Stabilizer. Exposure at: ✱ Picatinny, △ Fort Churchill, □ White Sands, ○ Panama. Initial Control, A; Final Control, B.

Specimens of fabrics (nylon and polyester) coated with PVC and neoprene by various coating methods at the GEN Thomas J. Rodman Laboratory in Rock Island, Illinois, (Garland, 1975), were sent to Panama for natural outdoor aging (open sunlight and rain forest). Results indicated that open sunlight aging had the more severe effect on all materials with the exception of the neoprene controls that actually improved somewhat in breaking strength. In all cases, specimens aged in the rain forest showed evidence of various types of fungus. It was decided that, in general, the coating material adds little or no strength to the base substrate, and differences in strength and elongation which exist within each type of substrate are due only to the variability within the materials.

All commercially available nylons suffer a loss in elasticity upon exposure outdoors. Ultraviolet light is the principal agent causing this damage. Efforts to improve weatherability of nylons include incorporation of a stabilizer or screening agents, and dilution of the basic polymer by means of additives.

In 1957, tropic deterioration of nylon filaments was the subject of a study of the British Tropical Testing Establishment conducted in Nigeria. Monofilament specimens of nylon 6-6 and nylon 6-10 were

exposed at four sites for a period of 2 years. Hot-dry (desert) conditions bleached nylon 6-6 and made nylon 6-10 yellow and opaque. Nylon 6-10 developed flaking and cracking under these conditions. Termites were found to cause damage to samples but there was no evidence that the material was consumed as a food source. Temporary changes in length were observed in nylon 6-6 but disappeared upon conditioning. At hot-humid sites, there was a slight loss in tensile strength and elasticity over the 2-year period and this loss was more apparent in the nylon 6-6. Under hot-dry conditions, tensile strength decreased to about one-fourth of its initial value and elasticity decreased to about one-half its initial value over the same exposure period.

Microbiological Degradation

Material damage caused by animals, particularly insects and rodents, is primarily of a mechanical nature, whereas the attacks by microorganisms are almost exclusively the consequence of chemical processes. This implies that the prevention of animal attack on materials involves either repelling or killing the animals. Microbial attack can also be prevented, at least in principle, by interfering with the chemical reactions which microorganisms bring about in or on their substrates. Microbial deterioration of materials has a much greater diversity, and thus there are more varied consequences than from those caused by animals. The microbial effects may vary from a slight lessening of the aesthetic value of the affected objects to the total destruction of every single useful property of the original material.

Polymer Degradation

Most basic polymers are not susceptible to attack, but additives increase vulnerability. Bennicelli (1957) and Heinisch and Kuhr (1957) reported on studies of fungus resistance of natural and synthetic rubbers. Both studies found that the amount of fungal growth was dependent on the amount of nonrubber constituents present. Leaching of natural rubber to remove nonrubber soluble components decreased susceptibility to fungal growth.

At the Thirteenth Conference on Prevention of Microbiological Deterioration of Military Materiel (1964), the Joint Tropical Research Unit announced that they were studying plastics and rubbers in Australia, because of fungal degradation problems in various locations in the tropics. Tests on white plasticized PVC showed excessive fungal growth on all materials except one, when exposed both in the open and in the jungle. The one exception was a specially formulated lot which contained no fungicide. This substantiated the claim that PVC is almost 100 percent inert to fungi. PVC will not support fungal growth, but when plasticizers, stabilizers and processing agents are added it may become susceptible to fungal growth.

One hundred sandbags of 12 different types were exposed at four locations in the Canal Zone (Ernst, 1969). The bags were exposed singly on the ground and in a simulated revetment type exposure. They were examined monthly for deterioration caused by fungi, insects (termites), rodents, and also for actinic degradation. A smaller series of bags was placed at the Yuma Proving Ground Desert Test site in Yuma, Arizona. Principal attention was given to the performance of the general polymeric materials under atmospheric exposure. In 14 months of exposure at Yuma Proving Ground, polyethylene, polypropylene, and cotton bags had failed to meet established criteria but several types of acrylic bags and PVC-coated fiberglass bags were still in satisfactory condition. In the Canal Zone, the only bags surviving 2 years of exposure were made of acrylic.

Dement (1976) conducted a study at Tropic Test Center to develop methods for accurately measuring material degradation, and to determine if detailed information on changes occurring in the material could be useful in defining major degrading factors. Three polymer materials, plasticized cellulose acetate, nylon and mylar, were exposed in artificial and natural environments. The artificial environments included chambers in which temperature and humidity were controlled (low microbial activity) and a vegetable compost pile (high microbial activity). Natural exposures were at three levels--buried, litter layer and 25 inches above ground--in a humid tropic forest.

The acetate samples in the compost pile showed an immediate and significant weight loss. Maximum loss occurred in 10 days as opposed to 30 days for air exposure and 50 days in litter exposure (figure V-17). Investigation showed that plasticizer loss was mainly responsible for the decrease in weight. Nylon samples lost about 4 percent of their original weights after 4 weeks of exposure and thereafter remained chemically stable. Mylar gave no evidence of any changes.

Portig, et al., (1974) reported the results of exposures of cotton, nylon, PVC, latex and steel at 16 sites in the Panama Canal Zone. The study was designed to characterize the degradative properties of the various sites. Results of site comparisons are presented in Section IV of this document. Deterioration curves for the exposed materials in different exposure modes are shown in figures V-18 through V-22.

Other Biological Effects

The marine-borer resistance of various experimental polymeric materials was evaluated by the Naval Research Laboratory (Bultman and Southwell, 1971). Twenty-five formulations of PVC, four non-PVC formulations (chlorosulfonated polyethylene, ethylenepropylene rubber,

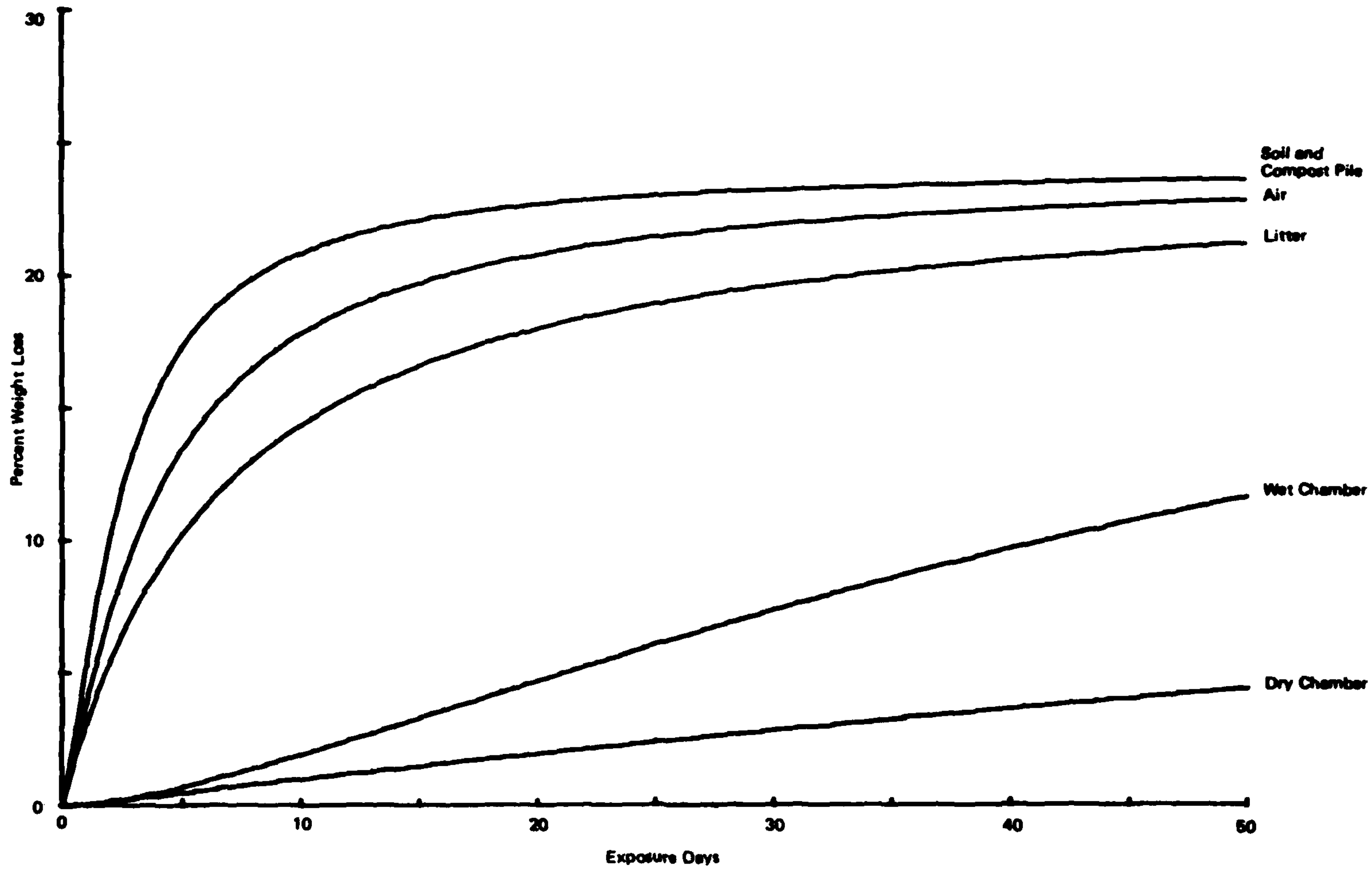


Figure V-17. Summary of Weight Losses for Cellulose Acetate in Different Exposure Modes.

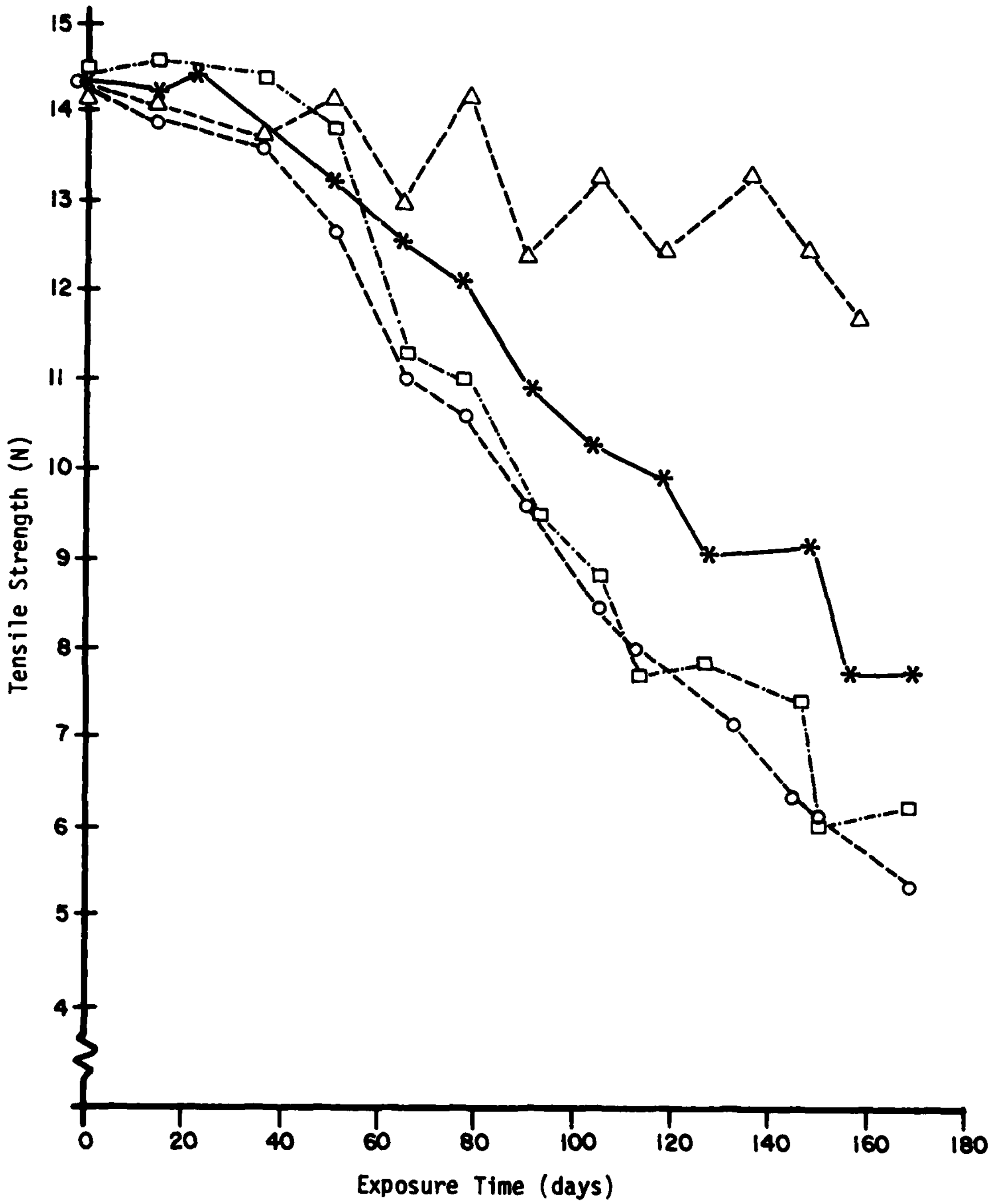


Figure V-18. Tensile Strengths for Cotton Material. Exposure Sites: ✱Open Inland, △ Shed, □ Forest, ○ Coastal.

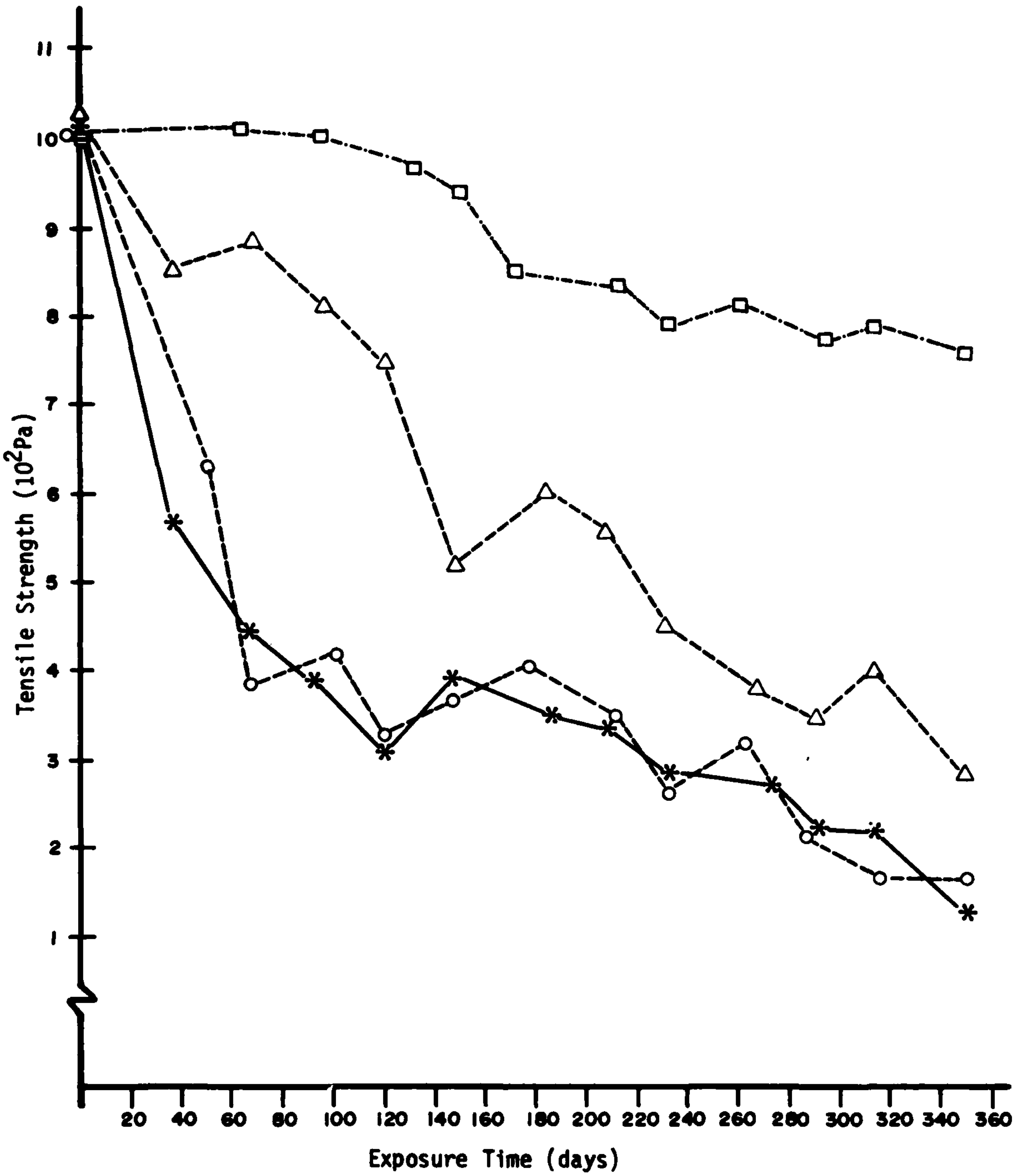


Figure V-19. Tensile Strengths for Nylon Material. Exposure Sites:
✱ Open Inland, △ Shed, □ Forest, ○ Coastal.

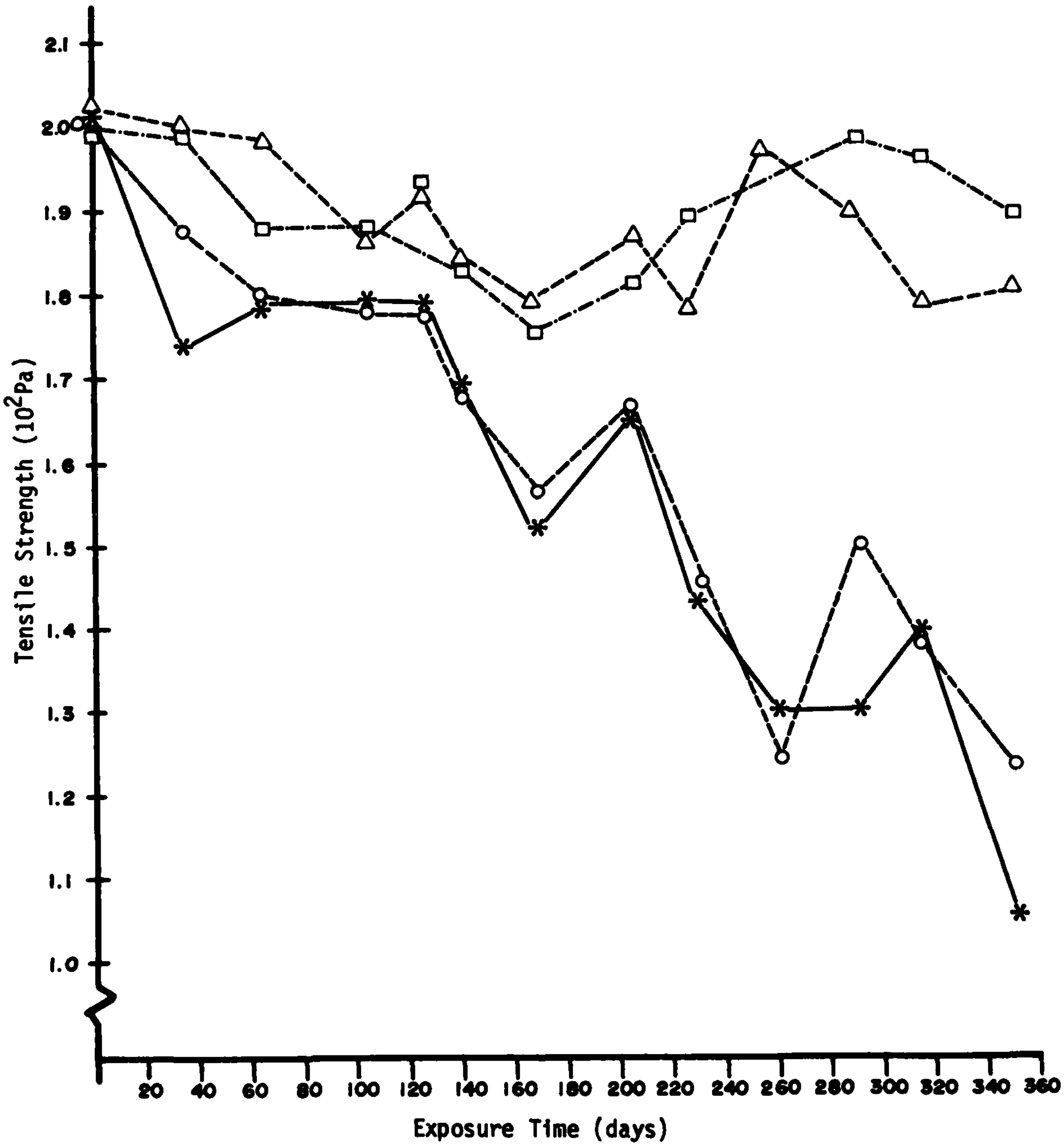


Figure V-20. Tensile Strengths for Polyvinyl Chloride Material. Exposure Sites: ✱ Open Inland, △ Shed, □ Forest, ○ Coastal.

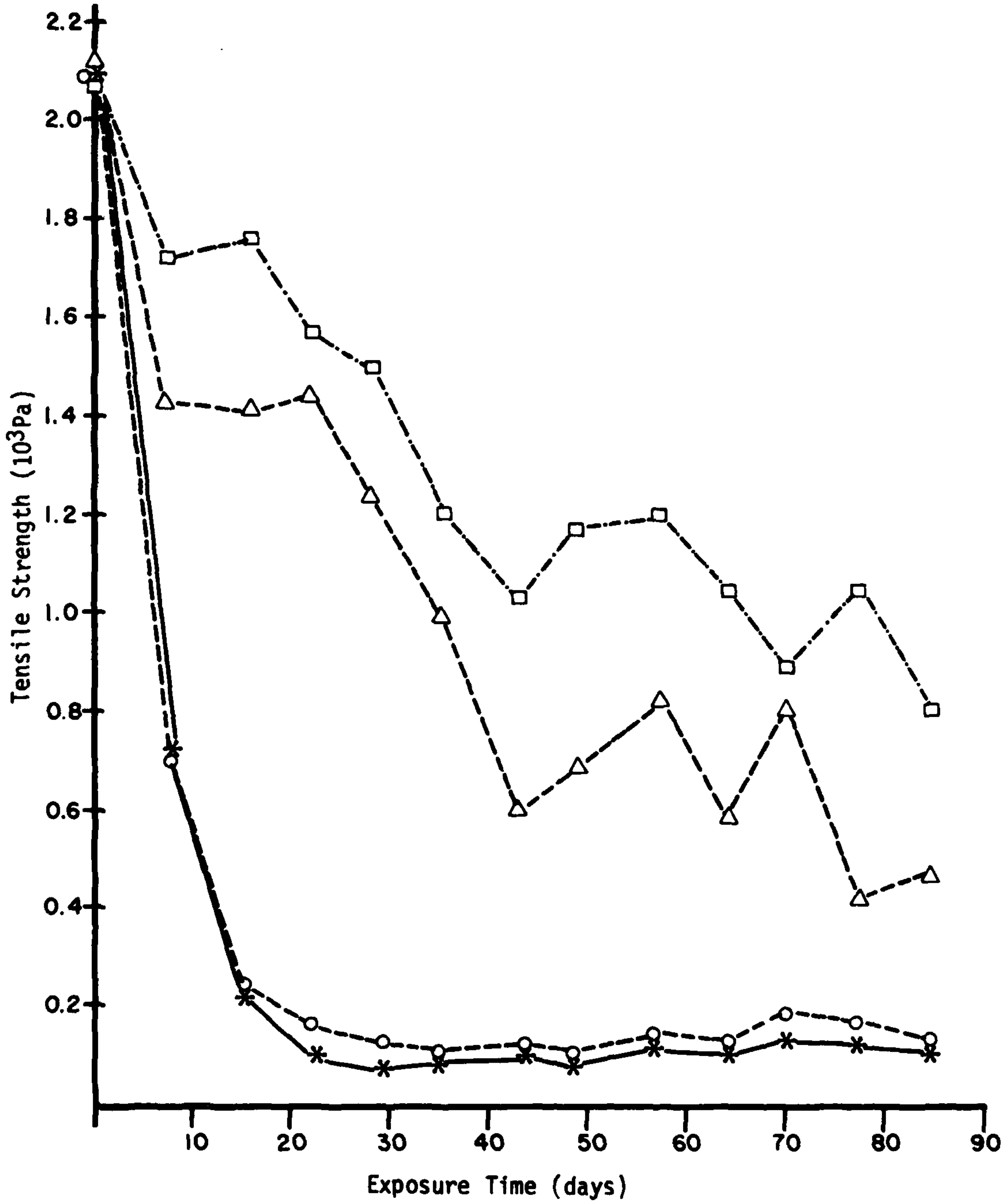


Figure V-21. Tensile Strengths for Latex Material. Exposure Sites: ✱ Open Inland, △ Shed, □ Forest, ○ Coastal.

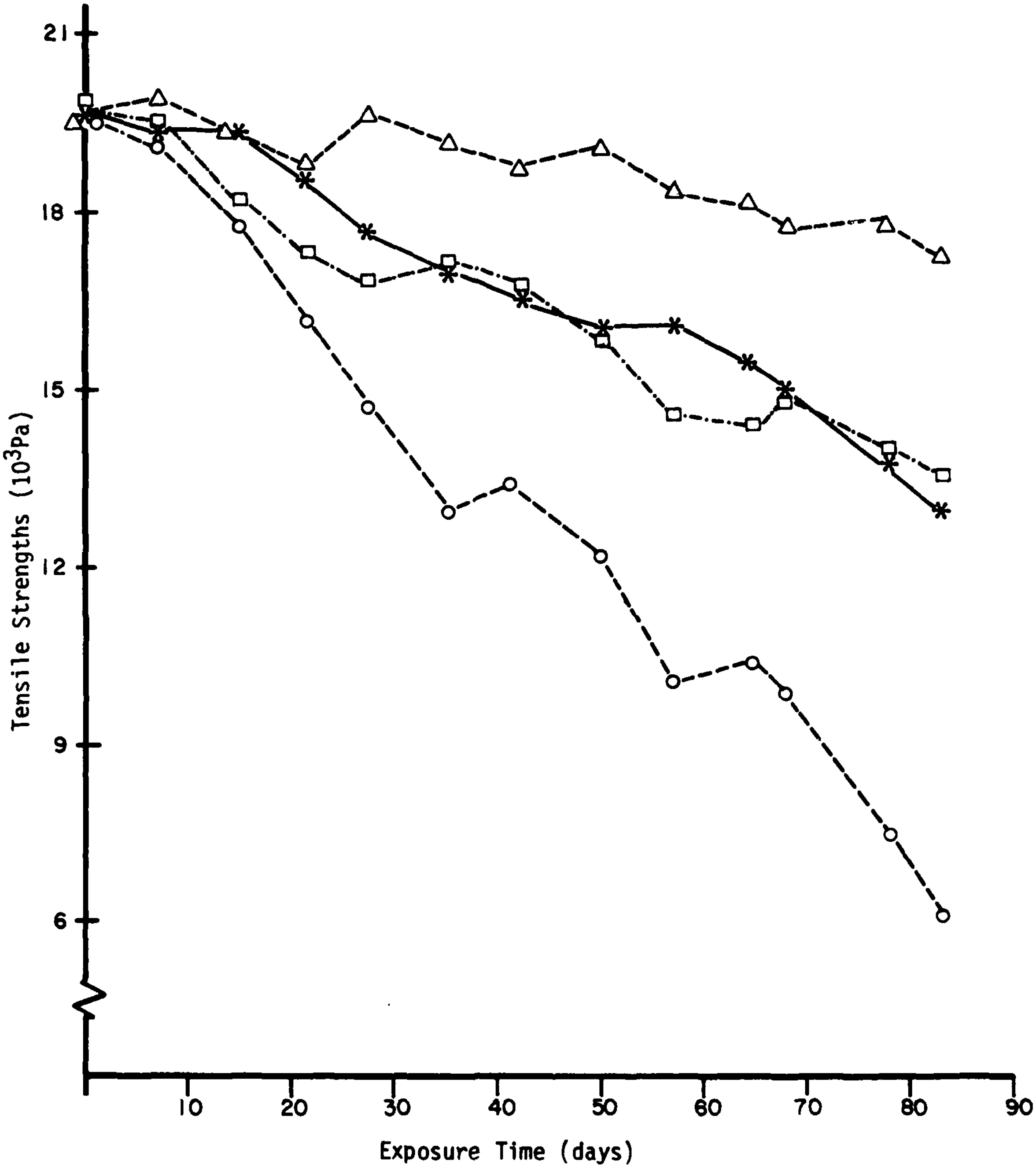


Figure V-22. Tensile Strengths for Steel Material. Exposure Sites: * Open Inland, △ Shed, □ Forest, ○ Coastal.

chlorinated polyethylene and crosslinked polyethylene), and one commercial plastic formulation (cellulose acetate-butyrate) were exposed in the Pacific Ocean at Naos Island, Canal Zone, and in the Caribbean Sea at Coco Solo, Canal Zone, for periods of 6 to 14 months. None of the formulations were completely immune to attack by both toredos and pholads, although the non-PVC polymers were more resistant to both than were the PVC formulations. The presence of inert fillers or toxicants or a change in plastic hardness in the PVC formulations had little effect on the amount of pholad damage. Teredo damage was not as extreme or extensive as pholad damage. The PVC formulations containing the inert, inorganic fillers were virtually undamaged by teredos; those containing toxicants were also relatively free of damage by these organisms. Creosote as a co-plasticizer protected one of the PVC formulations against teredos. The cellulose acetate-butyrate was heavily damaged by both teredos and pholads.

Termites readily attack polymers such as PVC. A number of PVC formulations with different plasticizers with and without toxicants were exposed to termites in the humid tropics (Bultman, et al., 1972; Southwell, et al., 1972). Formulations plasticized with dioctylphthalate were the most heavily attacked even when they contained toxicants. Formulations plasticized with tricresyl phosphate fortified with the ortho-isomer were the least damaged, either with or without toxicant present, although formulations with the para-isomer were nearly as good. The toxicant indone was found to be most effective and dieldrin the least effective in preventing termite attack. Physical modifications to PVC such as surface smoothness, increased thickness, and incorporation of mineral fillers provided modest to considerable improvement in resistance. There was a correlation between hardness and termite resistance. Increasing hardness from 10 to 30 (Shore D durometer scale) reduced the number of PVC failures by 86 percent. The soft flexible polymers, ethylene propylene rubber and clorosulfonated polyethylene were found to be more resistant to termite attack than the softest PVC.

C. PROTECTIVE COATINGS

For the most part, coatings exposed out-of-doors encounter more destructive influences than do those used on interiors. The deteriorative agents consist of extremes of temperature, moisture, sunlight and reactive gaseous elements of the atmosphere (oxygen, ozone, sulphur dioxide, hydrogen sulfide); marine exposure (salt spray); abrasive materials (sand, dust and dirt carried by winds and water); and biological agents such as fungi, bacteria, insects and marine organisms. Further contributions to deterioration may be made by the surface to be coated which may have porous, acid or alkaline, oily or resinous characteristics. The maximum decorative properties of a coating are usually observed immediately after a coating has dried. The maximum protective qualities of the coating, however, require a week to several months to develop. Deterioration begins shortly after application or after exposure to the particular deteriorative

conditions; but, because the process is slow, the reactions have usually been in progress for some time before they produce visible effects. Moisture and ultraviolet radiation are considered the two most degrading factors. Deterioration can be observed as discoloration, loss of gloss, chalking, cracking and alligatoring.

Tropic temperatures shorten the drying period, accelerate the continuous process of polymerization and oxidation, contribute to loss of plasticizers and to chalking, fading and other weathering effects.

Tropic humidity is capable of softening paints based with cellulose, alkyd and resins containing active hydroxyl (OH) and acid (COOH). Soluble pigments can cause blistering by absorbing moisture. Condensation of vapor to form dew is considered harmful to a paint film, apparently because such condensation more thoroughly wets the film, particularly below the surface, than do other forms of moisture.

The humid tropics of Panama receive abundant solar radiaton. The energy within the ultraviolet band of the solor spectrum has a more pronounced effect upon paint than any other. When such radiation strikes a paint film, it may accelerate reactions of oxidation and polymerization and cause pigments to discolor and chalk.

Salt carried in wind or deposited on surfaces can work its way under an unbroken paint film, destroy its adhesion and speed corrosion on metal surfaces. No known paint system will prevent completely the spread of corrosion although passivating pigments containing chromates greatly retard it.

Fungi and bacteria attack organic coatings, and tropic temperature and humidity characteristics create ideal conditions for growth of such organisms. Termites will destroy paint films in order to penetrate to the wood beneath. Marine organisms of the type that foul or bore will ruin an organic finish in the course of their life processes. Fouling organisms may colonize to the extent that the weight of their mass reaches hundreds of tons, reducing the speed of a ship as much as 25 to 50 percent. Seaplanes, at rest in fouling waters for as little as 2 weeks, can develop sufficient fouling to impede or even prevent take-off.

Hill, et al., (1973) evaluated four paints which were known to have different resistance to weathering and microbial growth by exposure to the tropic climates of Innisfail, Australia and the Panama Canal Zone. The testing was done by the Australian Defense Standards Laboratories whose objective was to compare the severity of conditions at these two sites. Wood and metal test panels with three coats of test paint applied to the front of the panel were exposed at an angle of 45^{o} to the vertical, facing north at Innisfail and south in the Canal Zone. While the exposure sites at Innisfail and the Canal Zone could be described as hot and wet according to AR 70-38, the daily

temperature and humidity variations were more extreme and the total precipitation was greater at the Innisfail site. It was concluded that the paints exposed at Panama chalked and lost their gloss more quickly, but checked and cracked more at Innisfail. Microbial colonization of the paints was similar at both sites.

Thompson (1970) evaluated 13 proprietary and 16 experimental self-curing, zinc-rich primers for durability properties. Test specimens were cold-rolled steel panels, sandblasted to white metal using fine silica sand or solvent-cleaned before priming. Panels were then sprayed to obtain a dry film thickness of 3.0 to 5.0 mils, and some were provided topcoats of a film thickness of 1.5 mils.

Initial temperate exposure at Aberdeen Proving Ground indicated that the site did not provide environmental conditions sufficiently corrosive to show major differences in protective properties in a reasonable length of time. Scored primers and topcoated primers were then exposed for 41 months at the breakwater site at Fort Sherman, Canal Zone. Test specimens were mounted in test racks at an angle of 30° from the horizontal. The specimens were evaluated approximately every 6 months for score, surface and substrate conditions. Conclusions were as follows:

> Zinc-rich primers provided better score protection in the marine environment than conventional alkyd, vinyl or epoxy primers.
>
> The primers with organic binders had better adhesion to solvent-cleaned steel than those with inorganic binders. However, for optimum corrosion preventive properties, a white sandblasted surface was required.
>
> Topcoating usually improved the protection provided by the organic zinc-rich primers while inorganic primers protected better without a topcoat. There were no major differences in the value of the three topcoats studied.
>
> The inorganic zinc-rich primers as a group provided better overall protection than the organic zinc-rich primers, especially those without topcoats. However, there was such a variance in performance (even among the inorganic primers) that selection of a specific binder type should be based on thorough evaluation under its intended exposure.

For over 15 years the Naval Civil Engineering Laboratory at Port Hueneme, California, has conducted research and evaluation on protective coating systems for use in protecting steel in the marine atmospheric environments of the Naval Shore Establishment. Brouillete (1972) sought to correlate coating performance of paints with environments of various test sites. The following were selected: a tropic site at Kwajalein, Marshall Islands; a subtropic site at Kaneohe,

Hawaii; and a temperate site at Port Hueneme, California. Samples were scribed and subsequently exposed. Most failed at the tropic site after 3 years of exposure and at the subtropic after 7 years, although some samples were giving fair to good protection at subtropic and temperate sites after 14 years of exposure. The epoxy paints tested lasted twice as long at the subtropic than at the tropic site. In general, vinyl paints tested lasted about 3 1/2 times longer at the subtropic than at the tropic site. Long periods of protection were found at the temperate site.

Crilly (1974) exposed 10 latex enamel paints on wood specimens for 1 year at the temperate and tropic sites. It was found that fungal growth was severe on all paints at the tropic site except on alkyd/acrylic paint and medium oil alkyd (Fed Spec TT-E-489F)* paint. Color retention was good on these paints but only the alkyd/acrylic paint maintained its original gloss after the 1-year exposure. It was recommended that because of ease of application and clean-up and lack of effects from environmental weathering, that the alkyd dispersion/acrylic emulsion paint be made available for Navy use.

D. WOOD

All cellulosic materials are degraded by two forms of biological activity in the humid tropics--microbial and termite attack. Rotting is the natural decay caused by microbial attack from the many varieties of fungi in the tropic soil and air. Termite attack results in rapid destruction of cellulose materials in humid tropic areas.

Gjovik and Davidson (1975) investigated the effectiveness of various chemical preservatives on southern pine sapwood stakes against fungal and termite attack in temperate and tropic climates. It was found that untreated pine had a life span of approximately 1 year in the Panama Canal Zone, 1.8 to 3.6 years in Mississippi and Florida, and 4 to 6 years in Wisconsin. Stakes treated with chromated zinc chloride lasted 5 to 7 years in Panama, 14 to 20 years in Mississippi, and 15 to 18 years in Wisconsin. Stakes treated with fluor chrome arsenate phenol had an average life span of 14 years in Panama and 24 years in Mississippi. Stakes in Wisconsin treated with similar retentions of the arsenate preservative had an average life span of 14 to 16 years. An interesting fact is that Mississippi has the same termite species as the Canal Zone, but they are not as destructive in the temperate site.

The Naval Research Laboratory (Bultman and Southwell, 1973) studied the biodegradation of treated and untreated woods in terrestrial environments of the Canal Zone. The studies covered exposure periods up to 158 months at three jungle exposure sites. In all, 115 natural woods and five wood preservatives were evaluated for resistance

*Federal Specification TT-E-489F, Enamel, Alkyd, Gloss (for Exterior and Interior Surfaces), 10 December 1970.

to subterranean termites and to above- and below-ground fungal decay. Of the 115 species of untreated wood, 37 survived the full 158-month exposure; of these, only five were considered to be highly resistant to all wood-degrading organisms present. Fungi below and near the ground-line were the most universally destructive organisms. Subterranean termites destroyed susceptible woods more rapidly, but eventually many more wood species were found to have higher natural resistance to termites than to fungi.

Wood density was an important factor in durability but was not the only requirement. Forty-one of the 65 hard, heavy woods tested (specific gravity greater than 0.7), were found to have high resistance to subterranean termites for 18 months. Of greater general interest, because of their more usable weight, were the medium and light density woods with high termite resistance. Ten species of the 32 medium density woods and two of the 14 light woods showed exceptionally high resistance, despite a low density.

Woods of medium and light weights found to have high termite resistance for the first 18 months of exposure were Bombacopsis quinata (cedro espino), Cariniana pyriformis (chibuga, albarco), Caryocar sp. (ajo), Chlorophora tinctoria (mora), Enterologium cyclocarpum (corotu), Guarea longipetiola (chuchupate), Pithecellobium mangense (una de gato), Swietenia macrophylla (mahogany), Tectona grandis (Burma teak), Cedrela mexicanna (cedro amargo) and Cordia alliodora (laurel negro).

Few species of soft woods appeared to be attractive to termites; stakes of Bursera simaruba and Dialyanthera otoba were completely destroyed before any of the other woods were significantly attacked. Southern pine and North American white oak were also especially susceptible to termite attack.

Termite infestation was not deterred by the presence of fungal activity in wood, but it was not determined whether fungal presence acted to accelerate attack. Certain chemical constituents in wood were definitely contributory to high resistance; one of the most effective seemed to be naturally occurring quinine. Silica, an important chemical affecting durability in marine environments, showed no significant effect on terrestrial durability.

No termite attack was observed on either creosote or pentachlorophenol-treated specimens during the 18-month test periods. These two chemicals are considered to be most effective for termite control. Table V-6 summarizes results of the series of studies.

E. METALS

The primary mechanism of degradation of metals is corrosion. There are several kinds of corrosion, each of which is caused by interaction of as many as 30 to 40 factors. Oxygen is the main

Table V-6. Comparison of Treated and Untreated Woods Exposed in Tropic Forests.

Materials: Preservative-Treated Woods Exposed in Terrestrial Environments			Degree of Damage*: Subterranean Termites				Fungi: Above Ground				Fungi: Groundline and Below			
Preservatives	Retention (lb/ft^3)	Wood	12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo	12 mo	30 mo	90 mo	158 mo
Whole creosote, grade 1, medium residue	8.4 - 10.1	Southern pine	0	0	0	0	0	0	0	0	0	0	1	0
Copper formate (water base, thermal reacted)	0.59 - 0.65	Southern pine	0	0	1	1	0	0	1	1	0	0	2	2
Pentachlorophenol, AWPA P9 (5% in Navy std fuel oil)	0.45 - 0.53	Southern pine	0	0	1	1	0	0	1	2	0	1	2	4
Tributyltin oxide (0.3% in No. 2 fuel oil)	0.027 - 0.029	Southern pine	0	1	2	x	0	1	5	x	0	2	5	x
Tributyltin oxide (0.6% in No. 2 fuel oil)	0.072 - 0.077	Southern pine	0	1	5	x	0	0	5	x	0	1	5	x
Osmose Salts, AWPA P5 (2% in H_2O)	0.59 - 0.65	Southern pine	0	0	1	1	0	1	2	4	0	2	2	5
Osmose Salts, AWPA P5 (3% in H_2O)	0.70 - 0.78	Cativo	0	1	x	x	2	3	x	x	3	5	x	x
Five of the Most Resistant Natural Woods Exposed in Terrestrial Environments														
Botanical Name	Common Name	Source												
Guajacum officinale	Lignum vitae	Central America	0	0	0	0	0	0	0	1	0	1	1	2
Dalbergia refusa	Cocobolo	Panama	0	0	0	0	0	0	1	1	0	1	2	2
Vouacapoua americana	Acapu	Brazil	0	0	0	0	0	1	1	1	0	1	2	2
Ocotea rodiei	Greenheart	Guyana	0	0	1	1	0	1	1	1	0	1	2	2
Tabebuia guayacan	Guayacan	Panama	0	0	1	0	0	1	1	2	0	1	2	3

*0 - none, 1 - trace, 2 - slight, 3 - moderate, 4 - heavy, 5 - very heavy, x - all specimens were removed or destroyed before this inspection because of low resistance to fungi or termites or both.

contributor to corrosion of metals such as aluminum, magnesium, copper, steel and zinc. Some of the oxides formed are beneficial because they prevent further corrosion by forming thin films on the metal which prevent or retard further reaction. This is true of aluminum, chromium, nickel, and various stainless steels. The formation of such oxides--in the case of aluminum and its alloys--by a commercial process called anodizing, produces an extremely adherent and abrasion resistant surface coating of aluminum oxide. Oxidation or rust produced on mild steels can be caused by direct combination with atmospheric oxygen, but such attack is slow at low temperatures. For rapid corrosion of iron and steel, the presence of moisture and elevated ambient temperatures is essential. With water present, either as a liquid or a vapor, a fast chemical reaction takes place and one or a number of the possible oxides of iron are formed. As noted, the oxides of aluminum and some other metals prevent further corrosion but such an effect is rarely observed with iron or nonstainless steels. The reason for this is that oxides of aluminum and other resistant metals are crystalline and occupy the same area as base metals; there is no overcrowding of the surface and, therefore, the oxide crystals sheath the base metal. With iron and low alloy steels, the corrosion products occupy a greater area than the base metal and do not form a tough impervious film. The corrosion products fall off, resulting in exposure of new material to attack.

Portig, et al. (1974), found that steel deterioration curves were best approximated either by straight lines or by parts of exponential curves where they are almost straight (figure V-22). Steel reacts strongly to moist salt (coastal) air. The high humidity of the forest, frequently coupled with permanent wetness of the samples, was not as deteriorative as the radiation and wet-dry cycles at the open sites. Protection provided by shelter or natural canopy resulted in lower tensile strength loss.

Frankford Arsenal (Menke, 1969, unpublished paper) prepared samples of panels of AZ31 magnesium, 1020 steel, and 5086 aluminum by blasting with 80-mesh steel grit. The panels were preheated in an oven at 400°F (204°C) for 30 minutes, fluidized bed coated with Armstrong 303 0 D epoxy, and cured at 400°F (204°C) for 30 minutes. Coating thickness on the magnesium panels was 7 to 9 mils and on the steel and aluminum panels, 8 to 10 mils. The panels were exposed at a marine site in the Panama Canal Zone. The magnesium panels underwent 27 months of exposure; the steel and aluminum panels, 61 months.

The effects of the Canal Zone environment on the fluidized bed epoxy-coated magnesium were very severe. Some coating remained on the basis metal, suggesting that greater protection might be possible if a better edge covering material were used. Once the coating was penetrated, corrosion products began to form and the coating as well as the basis metal rapidly corroded.

On steel, initial edge failure proved damaging to the effectiveness of the coating. Corrosion proceeded inward to the extent that some panels split in half. The influence of the corrosion occurring under the coating was intensive enough to change the color appearance of the coating and to push the basis metal apart. The coating was still present on the surface of the steel panels after 61 months of exposure.

On aluminum, most of the coating had blistered away after a 61-month exposure. A thin film of epoxy remained but little corrosion of the basis metal was noted. Table V-7 shows inspection results throughout the test period.

Southwell, et al. (1964), of the Naval Research Laboratory conducted studies on corrosion resistance of three alloys of aluminum and two alloys of magnesium following exposure up to 16 years in five natural tropic environments. These included seawater immersion, freshwater immersion, and exposure to tidal seawater, a tropic marine atmosphere, and a tropic inland atmosphere. Aluminum 1100, aluminum alloy 6060-T, and magnesium alloy AZ31X were exposed to each of the environments listed. In addition, Alclad aluminum 2024-T and magnesium alloy AZ61X were exposed to two tropic atmospheres. Weight loss, pitting, and change in tensile properties were measured to show the extent of corrosion for each of these materials (table V-8). Aluminum alloys demonstrated extremely high resistance to each environment, with the exception of tropic fresh water in which case serious pitting occurred. Alloy 6061-T demonstrated some superiority to aluminum 1100 in all environments.

Similar studies on corrosion of nickel and nickel-copper alloys were reported for exposure periods of 1, 2, 4, 8 and 16 years (Southwell and Alexander, 1967). Data collected included weight loss, pitting, change in tensile strength of simple plates, and weight loss of galvanic couples. Corrosion in the tropics was compared with exposure results from temperate latitudes in the United States, and generally tropic corrosion was appreciably higher. With respect to pitting, the high nickel alloys developed severe early pitting under seawater. However, the initial high penetration rates leveled off to very low rates after the first 1 to 2 years of exposure. Comparison under tropic seawater of monel and copper-nickel with various other nonferrous metals showed copper-nickel with comparatively high corrosion resistance, but monel with the lowest seawater resistance of the group. Galvanic corrosion results showed the long-term efficiency of carbon steel anodes in cathodically protecting nickel-copper alloys in seawater. Additional galvanic data revealed that considerable anodic corrosion can be induced in a normally sea-resistant metal if coupled with certain nickel alloys. The nickel metals were highly resistant to corrosion in tropic atmospheres. There was no measurable pitting in these terrestrial exposures and only small weight losses. The

Table V-7. Observations on Fluidized Bed Epoxy-Coated Panels Exposed in Panama.

Exposure	1020 Steel	5086 Aluminum	AZ31 Magnesium
6 months	Loss of gloss	Loss of gloss	Blistering along edges and on panel surface. Some corrosion.
12 months	No change	No change	15-30% of panel corroded.
21 months	Corrosion along edges.	No change	Basis metal beginning to corrode away.
27 months	Severe corrosion around holes and along edges. Rust rundown from holes.	Some change in color.	80% of panel corroded. 5-10% of basis metal corroded away.
33 months	Epoxy is peeling from edges.	Severe dulling of the coating.	
40 months	Corrosion extending in from edges and holes.	Some epoxy is removed near the edges.	
47 months	50% of panels are corroded from the edge inward.	Epoxy is flaking Some corrosion along edges.	
53 months	75% of panels are corroded from the edge inward.	All panels exhibit blistering and flaking.	
61 months	All panels are corroded from the edge inward. Surface color is rusty red.	Minimal coating remaining and minimal corrosion noted.	

Table V-8. Evaluation of Corrosion Damage of Light Metals Exposed in Five Tropic Environments in the Canal Zone.

Metal	Exposure	Weight Loss (g/dm^2) 1 yr	2 yr	4 yr	8 yr	16 yr	Average Penetration (mils) (a) 1 yr	2 yr	4 yr	8 yr	16 yr	Tensile Strength Loss (%) 8 yr (b)
	Immersion											
	Sea Water	0.19	0.27	0.45	0.42	0.67	0.28	0.39	0.66	0.61	0.97	2
Aluminum 1100	Mean Tide	0.04	0.08	0.17	0.22	0.37	0.06	0.11	0.25	0.31	0.53	1
	Fresh Water	0.28	0.65	0.95	1.61	3.47	0.41	0.95	1.37	2.34	5.04	4
	Atmospheric											
	Marine	0.006	0.024	0.008	0.013	0.075	0.01	0.04	0.01	0.02	0.11	0
	Inland	0.002	0.017	0.000	0.024	0.052	0.00	0.03	0.00	0.03	0.08	0
	Immersion											
	Sea Water	0.19	0.33	0.39	0.50	0.63	0.28	0.48	0.56	0.73	0.91	0
Aluminum 6061-T	Mean Tide	0.03	0.05	0.07	0.09	0.20	0.04	0.07	0.10	0.13	0.29	0
	Fresh Water	0.06	0.16	0.31	0.53	1.03	0.08	0.23	0.45	0.77	1.50	1
	Atmospheric											
	Marine	0.021	0.037	0.051	0.018	0.077	0.03	0.06	0.08	0.03	0.11	1
	Inland	0.010	0.028	0.007	0.008	0.059	0.02	0.04	0.04	0.01	0.09	1
Alclad 2024-T	Atmospheric											
	Marine	0.017	0.028	0.009	0.012	0.090	0.03	0.04	0.02	0.02	0.14	1
	Inland	0.009	0.009	0.000	0.002	0.050	0.02	0.02	0.00	0.01	0.07	2
	Immersion					(e)						(f)
	Sea Water	3.24	8.69	6.84	13.77	-	7.21	19.32	15.21	30.62	-	-
Magnesium AZ31X (c)	Mean Tide	6.04	8.90	17.55	17.60	-	13.44	19.78	39.03	39.14	-	-
	Fresh Water	1.73	2.45	3.44	5.48	-	3.84	5.45	7.64	12.18	-	5
	Atmospheric											
	Marine	0.48	0.85	1.62	3.54	6.77	1.06	1.89	3.60	7.88	15.47	4
	Inland	0.27	0.54	0.70	2.05	4.23	0.61	1.20	1.56	4.55	9.50	5
	Atmospheric											
Magnesium AZ61X (d)	Marine	0.22	0.59	0.16	2.84	5.35	0.48	1.27	0.35	6.19	11.66	11
	Inland	0.17	0.39	0.07	1.48	3.52	0.36	0.86	0.15	3.24	7.68	13

(a) Calculated from weight loss and specific gravity .
(b) Percent change in tensile strength calculated on basis of 1/4-inch-think metal and average of four tests for underwater specimens, and 1/16-inch-thick metal and average of three tests for atmospheric specimens.
(c) Former ASTM designation - 18X.
(d) Former ASTM designation - 8X.
(e) Because of high rate of corrosion magnesium panels were exposed for only eight years in these environments.
(f) Panels too badly corroded to test.

losses that were measured however, showed increasing resistance of the metals with increasing nickel content. Table V-9 summarizes results.

During a 16-year period Southwell and Alexander (1969) exposed 20 structural ferrous metals to a seawater site (Pacific Ocean, Fort Amador), a fresh water site (Gatun Lake) and a brackish water site (Miraflores Lake) in the Canal Zone. It was found that after 2 years of exposure, corrosion rates of most ferrous metals stabilized to constant values. The corrosion rates of various low alloy steels were found to be four times greater for samples exposed in tropic seawater than for samples exposed in tropic fresh water. Steel corrosion losses in tropic and temperate latitudes during this 16-year period showed similar corrosion-time relations for the different latitudes but slightly higher final rates for the tropic seawater exposure. The tropic seawater value put a useful upper limit to the corrosion rates of similar samples in all environments.

Pearlstein and Teitell (1971) compared double-layer nickel deposits with single-layer deposits (with chromium flash topcoats) for corrosion protection of steel exposed at various Fort Sherman test site areas. It was found that the double-layer nickel-plated steel was more resistant to corrosion than single-layer nickel at the tropic marine and open field test sites. There was no advantage to the double-layer at the rain forest test site. Forty μm (1.6 mil) total thickness of double-layer nickel was completely protective to steel at the open field and rain forest sites for tropic exposure periods of over 35 months, whereas the 20 μm (0.8 mil) thickness was not; at the Marine test area the 40 μm specimens had only slight basis metal attack during the same exposure period. Elimination of the chromium flash topcoat on the 40 μm nickel deposits appeared to improve resistance to basis metal attack but greatly reduced surface tarnish resistance. It was also found that a semibright nickel electrodeposit with an electroless nickel topcoat was superior in corrosion protection to the conventional double-layer nickel electrodeposits of the same total thickness. However, the electroless nickel deposits tarnished badly at the tropic exposure sites.

The Naval Research Laboratory conducted a study from 1946 to 1962 to determine the role of marine organisms in structural steel deterioration in seawater. Steel samples were exposed in waters in the Canal Zone, Florida and Maryland. Results showed that fouling is an important factor in reducing normal corrosion of steel. The mechanism of this reduction was a decrease in oxygen diffusion to the metal surface caused by fouling organisms. The adverse effect of fouling was that the anaerobic conditions produced at the metal surface allowed sulfate-reducing bacteria to attack the surface and establish a steady deterioration rate of 2 to 3 mils-per-year. This steady state rate was observed in both tropic and temperate waters. Metal weight losses

Table V-9. Tabulation of Corrosion Damage for Nickel-Copper Alloys and Comparison Metals.

Symbol	Metal	Exposure	Weight Loss (g/dm^2) 1 yr	2 yr	4 yr	8 yr	16 yr	Average Penetration (mils) 1 yr	2 yr	4 yr	8 yr	16 yr	Tensile Strength Loss (%)* 16 yr
A	Nickel 99%	Immersion											
		Sea Water	5.40	7.55	11.80	28.40	43.40	2.40	3.35	5.22	12.60	19.30	9
		Mean Tide	0.78	1.30	2.99	5.77	9.89	0.35	0.58	1.33	2.56	4.39	2
		Fresh Water	0.00	0.00	0.00	0.03	0.08	0.00	0.00	0.00	.01	0.04	1
		Atmospheric											
		Marine	0.02	0.03	0.06	0.13	0.26	0.01	0.02	0.03	0.06	0.12	0
		Inland	0.01	0.04	0.06	0.09	0.21	0.01	0.02	0.03	0.04	0.09	0
B	Monel (cold rolled) 67 Ni- 30 Cu- 1.8 Fe	Immersion											
		Sea Water	3.67	5.14	9.35	14.2	19.5	1.64	2.29	4.18	6.32	8.66	8
		Mean Tide	0.23	0.50	1.11	3.02	6.00	0.10	0.22	0.50	1.34	2.67	2
		Fresh Water	0.00	0.20	0.03	0.25	1.30	0.00	0.09	0.01	0.11	0.61	1
		Atmospheric											
		Marine	0.10	0.08	0.14	0.25	0.49	0.04	0.04	0.07	0.17	0.22	2
		Inland	0.02	0.05	0.08	0.14	0.30	0.01	0.03	0.04	0.06	0.13	1
C	Monel (hot rolled) 67 Ni- 30 Cu- 2.1 Fe	Immersion											
		Sea Water	4.68	5.46	9.05	14.40	18.72	2.09	2.44	4.05	6.44	8.37	-
		Mean Tide	0.25	0.63	1.58	3.09	5.74	0.11	0.28	0.71	1.38	2.57	-
D	Copper-nickel 30 Ni- 69 Cu	Immersion											
		Sea Water	1.15	2.34	3.13	3.38	5.11	0.51	1.03	1.38	1.49	2.25	1
		Mean Tide	0.19	0.31	0.61	0.97	1.71	0.08	0.14	0.27	0.43	0.75	1
		Fresh Water	0.38	0.60	1.20	2.18	2.96	0.17	0.26	0.53	0.96	1.31	1
		Atmospheric											
		Marine	0.08	0.14	0.27	0.52	0.93	0.03	0.06	0.12	0.23	0.41	1
		Inland	0.04	0.11	0.18	0.30	0.62	0.02	0.05	0.08	0.13	0.27	1
E	Nickel silver 18 Ni- 64 Cu 17 Zn	Atmospheric											
		Marine	0.09	0.15	0.26	0.49	0.83	0.04	0.06	0.12	0.22	0.37	0
		Inland	0.04	0.09	0.16	0.29	0.63	0.02	0.04	0.07	0.13	0.28	0
F	Copper 99.9%	Immersion											
		Sea Water	2.74	5.03	5.95	12.1	13.6	1.21	2.22	2.62	5.33	6.02	5
		Mean Tide	1.47	1.85	4.30	2.45	2.99	0.65	0.82	1.90	1.08	1.32	1
		Fresh Water	0.50	0.81	1.29	1.86	2.33	0.22	0.36	0.57	0.82	1.03	2
		Atmospheric											
		Marine	0.37	0.52	0.86	1.29	1.73	0.17	0.23	0.38	0.57	0.77	4
		Inland	0.18	0.26	0.34	0.43	0.60	0.08	0.12	0.15	0.19	0.27	1
		Immersion											
G	Al-bronze	Sea Water	0.39	0.75	1.25	1.58	2.62	0.19	0.36	0.60	0.76	1.26	3
H	6061 Al	Sea Water	0.19	0.33	0.39	0.50	0.63	0.28	0.46	0.56	0.73	0.92	1
J	Lead	Sea Water	1.67	3.37	4.93	8.18	14.0	0.58	1.17	1.72	2.85	4.88	0
K	Zinc	Sea Water	3.18	4.73	6.03	9.08	15.7	1.76	2.61	3.33	5.01	8.23	3

*Percent tensile losses are for samples of 1/4-inch thickness for immersion exposure and 1/16-inch thickness for atmospheric exposure.

after 1 year were: Naos Island, Pacific, Canal Zone--10.6g/dm^2; Coco Solo, Canal Zone--7.3g/dm^2; Chesapeake Bay, Maryland--7.2g/dm^2; St. Andrew Bay, Panama City, Florida--11.0g/dm^2; Fleming Key, Key West, Florida--7.4g/dm. The corrosion rates were dependent on local environmental conditions and not tropic versus temperate differences.

Southwell and Bultman (1974) also conducted studies from 1946 to 1962 to determine corrosion rates for various structural steels at an inland and an Atlantic marine site in the Canal Zone. Rates were compared with those published for similar materials in temperate latitudes. Findings were that corrosion rates of structural steels for an 8-year exposure were 1.5 to 2.2 times higher in the tropic marine atmosphere of the Canal Zone (Cristobal) than in a similar temperate marine environment (Kure Beach, North Carolina); corrosion weight loss of mild steel was 1.7 times higher in the tropic marine site than the inland tropic site (Miraflores); copper-bearing steel was less effective in reducing corrosion in the tropics than in temperate zones; 2-percent and 5-percent nickel steel resisted corrosion 45 to 49 percent better than copper-bearing steel; the corrosion resistance of chromium steel was comparable to that of nickel (47 to 64 percent better than copper steel); four proprietary low alloy steels displayed high resistance to tropic atmospheric corrosion (36 to 49 percent better than copper steel).

Pelensky et al. (1976), exposed galvanic couples of various metals (aluminum, brass, magnesium, monel, steel, stainless steel, titanium alloys) to the tropic atmosphere and soil at Fort Sherman and in seawater at Coco Solo on the Atlantic Coast from 1973 to 1977. Preliminary results from the 2- and 4-month exposure periods indicated that least galvanic action occurred in the atmosphere and greatest galvanic action occurred in seawater. Titanium was not affected in any of the three environments. Monel and Type 316 stainless steel were found resistant to galvanization in open air and soil. Pitting of monel occurred in seawater but was reduced in quantity when samples were coupled with the more anodic alloys (magnesium, aluminum, brass and steel).

SECTION VI. TROPIC DEGRADATION OF MATERIEL

A. INTRODUCTION

This section summarizes the results of past tests of military materiel in the humid tropics. All tests were conducted by the US Army Tropic Test Center in the Panama Canal Zone unless noted otherwise in the text. The purpose of the section is to provide examples of materiel problems in a hot, humid environment; therefore, information is biased toward those systems that exhibited some form of degradation or reduced performance during testing. A complete bibliography of USATTC reports (Davidson, 1979) is available.

B. CHEMICAL EQUIPMENT

Chemical materiel testing at USATTC is restricted to defensive equipment such as protective masks, chemical agent detectors, smoke and riot control agent munitions and related devices.

A survey of past tests of chemical items indicates that moisture, corrosion and microbiological activity have pronounced effects on chemically-related materiel. The high temperature and humidity associated with the humid tropics may cause overgarments and shelters, which provide personnel protection, to become excessively uncomfortable. Electrical components, mechanical items such as fans and chemical/biological filters are items particularly susceptible to corrosion, biological and humidity effects. Protective entrances may have adhesive failures due to humidity. Zippers on the entrance doors corrode or fail through wear.

Collective Protection Equipment

Boylston and Vaughn (1968) tested the suitability of the XM15 Collective Protector in a humid tropic environment, with emphasis on performance and reliability after storage. The system functioned reliably throughout the test; however, high humidity and temperature, combined with equipment noise, created human factors problems which eventually decreased operator efficiency.

Donaldson (1972) reported on a tropic integrated engineering and service test of the XM51 CB Protective Shelter. The test was terminated after 6 months because of safety hazards, deterioration of materials caused by environment, discomfort in the shelter from high humidity, and excessive maintenance requirements. Environmentally induced deficiencies and shortcomings were found as follows:

> Water condensed in sensing tubes and because of low points pooled within the tubes. This caused blockage, and as the tubes lead to air pressure switches designed to register shelter and ambient air pressure differences, the mask alarm malfunctioned. The alarm was designed to alert personnel to don masks whenever a condition of low pressure existed for a period of at least 30 seconds.

The orifices of these same tubes were unprotected by screening and insects entered, carrying dirt and foreign matter with which to build nests. Pressure switches failed to operate when the tubes filled up and became blocked.

Relative humidity could not be maintained below 70 percent and personnel complained of being chilled within the shelter.

A condensate drain filled with dirt, insects and fungus, causing condensate to drain instead from the corners of the trailer and to pool to a depth of 1 inch on the floor of the environmental control cabinet.

Exposure to heat shrunk coverings on electrical cables causing tearing of the covering at the point of entry into an electrical connector.

During periods of normal precipitation, water pooled to a depth of 4 inches on the trailer top. Water then seeped through the cover to the underlying equipment.

Movement along the trailer side rails, required for performance of maintenance, erection, deflation and stowage operations, was restricted caused by the construction of the trailer and then aggravated by slipperiness caused by tropic humidity.

Although deficiencies and shortcomings were corrected, a Development Test II of the M51, CB, Collective Protection Shelter System (Ellenberger, 1975) still listed problems attributable to the humid tropic environment. A deficiency reported was that of a water film developing over the orifices of sensing tubes during rains, preventing the pressure sensing unit from functioning when a low pressure was reached inside the shelter. Holes at joints in the shelter fabric allowed rain to enter the trailer and, as drainage was not adequate, rusting resulted.

Two Modular Collective Protection Equipment (MCPE) Systems were tested in the Canal Zone under tropic climatic conditions (Novack, et al., 1976). Several environmentally based deficiencies and shortcomings were reported:

The XM5 static frequency converter collected moisture and electronic circuitry developed corrosion deposits. The corrosion caused degradation of performance sufficient to warrant removal of the items from the test.

Wires inside special purpose electrical cables corroded and dissolved at the points of attachment to cannon plugs.

Weight increases ranging as high as 6 pounds, 10 ounces, for gas filters and 1.5 ounces for particulate filters were noted

throughout the test period. Weight fluctuation was considered to be the result of moisture take-up and release by the filtration material. No degradation in filter performance was indicated, but it was recommended that the filters be challenged with live agent in a controlled test chamber to verify filter efficiency.

Protective Masks

Protective masks are subject to adverse environmental effects during exposure. Mask lenses discolor and become obscured, insects build nests, lay eggs and eat through packaging. Chemical protection can decrease because of changes in composition of the filter materials caused by heat and moisture.

Novack, et al., (1976) conducted a 2-month exposure test of various candidate materials for use in the XM29/30 Protective Masks. The objective was to provide data for preliminary evaluation of material suitability in the tropic environment. Test items included an XM29 mask completely assembled with NATO C1 canister in carrier; an XM29 facepiece, viton/urethane-coated, nonirradiated lens, with head harness, in carrier; two aerosol filters, parallel pleated, one with silicone and the other with urethane edge seal; four silicone slab samples; and a modified C1 canister with NATO thread and silicone edge seal aerosol filter. The test items were placed under open-sided covered storage conditions on a wooden pallet approximately 4 inches off a concrete pad.

All items except the XM29 facepiece of viton/urethane-coated silicone and the Modified C1 canister showed immediate deterioration.

The assembled mask in carrier and the urethane-coated facepiece with irradiated lens showed the most discoloration along with development of a lens film.

All aerosol filter material and silicone materials were attacked by fungal organisms, an example of which is shown in figure VI-1. No such growth occurred on the urethane edge seal of the aerosol filter.

Slight increases in weight noted in the XM29 mask canister and a C1 canister were attributed to the hygroscopic nature of the gas filtration material within.

Figure VI-1. Sporulating Fungus on the Surface of a Silicone Slab Sample.

The silicone slab samples exhibited peeling/delamination as well as some loss in transparency due to fungus. There was evidence of some insect damage on filter material.

Chen (1978) evaluated results of a 5-year tropic environmental/surveillance test on the M25A1 Protective Tank Mask, conducted to determine effects of storage in the humid tropics on the physical characteristics and functional capabilities of the mask. Minor deterioration was found on both the rubber facepiece and the nosepiece of the mask after 5 years of warehouse and barracks storage. Visual inspections of the masks in warehouse storage showed them to be covered by a yellowish material (see figure VI-2) while those from barracks storage exhibited a white chalky material (figure VI-3). Examination of both substances showed no presence of fungi and infrared spectra showed similarity to that of natural rubber. While some of the substance was easily removed by use of soap and water, use of abrasives and hard scrubbing was required on facepieces. After removal from storage, the masks were subjected to a wear test and showed no deterioration in functional capabilities of mask parts. Following the wear test, mask canisters were weighed, and the weights of individual canisters had increased by over 200 grams.

Riot Control Agent

Zylstra (1976) summarized results of a surveillance test of riot control agent CS2 conducted in arctic, desert, temperate and tropic test sites. The CS2 was packaged in bags and stored in drums and in plastic bottles packed in a wooden box. Eight cyclic tests were conducted over a period of 5 years, each test consisting of a visual inspection, laboratory analysis, and a M3 disperser firing of the stored CS2. In the Canal Zone, bottled CS2 met criteria for microscopic particle size, agglomeration, flow property, apparent density, composition, and capability to reaerosolize after wetting. Bagged samples met criteria except for flow property and reaerosolization after wetting. The flow property failure was considered to be environmentally caused.

Chemical Detections

A surveillance/environmental test of the ABC-M8 Chemical Agent Detector Paper was conducted at Fort Greely, Alaska; Yuma Proving Ground, Arizona; Edgewood Arsenal, Maryland; and Fort Clayton, Canal Zone (Zylstra, Frese, 1971). The purpose of the test was to determine the effects of long-term environmental storage on performance of the M8 paper. Testing at Arctic Test Center (Fort Greely) was conducted between December 1965 and January 1968. At the other test locations, testing was extended through May 1979. Deseret Test Center (Dugway) conducted agent tests in the laboratory after exposure at the environmental sites. It was concluded that the M8 paper can be stored for 2 years in the arctic and 5 years in the desert, temperate, and tropic environments.

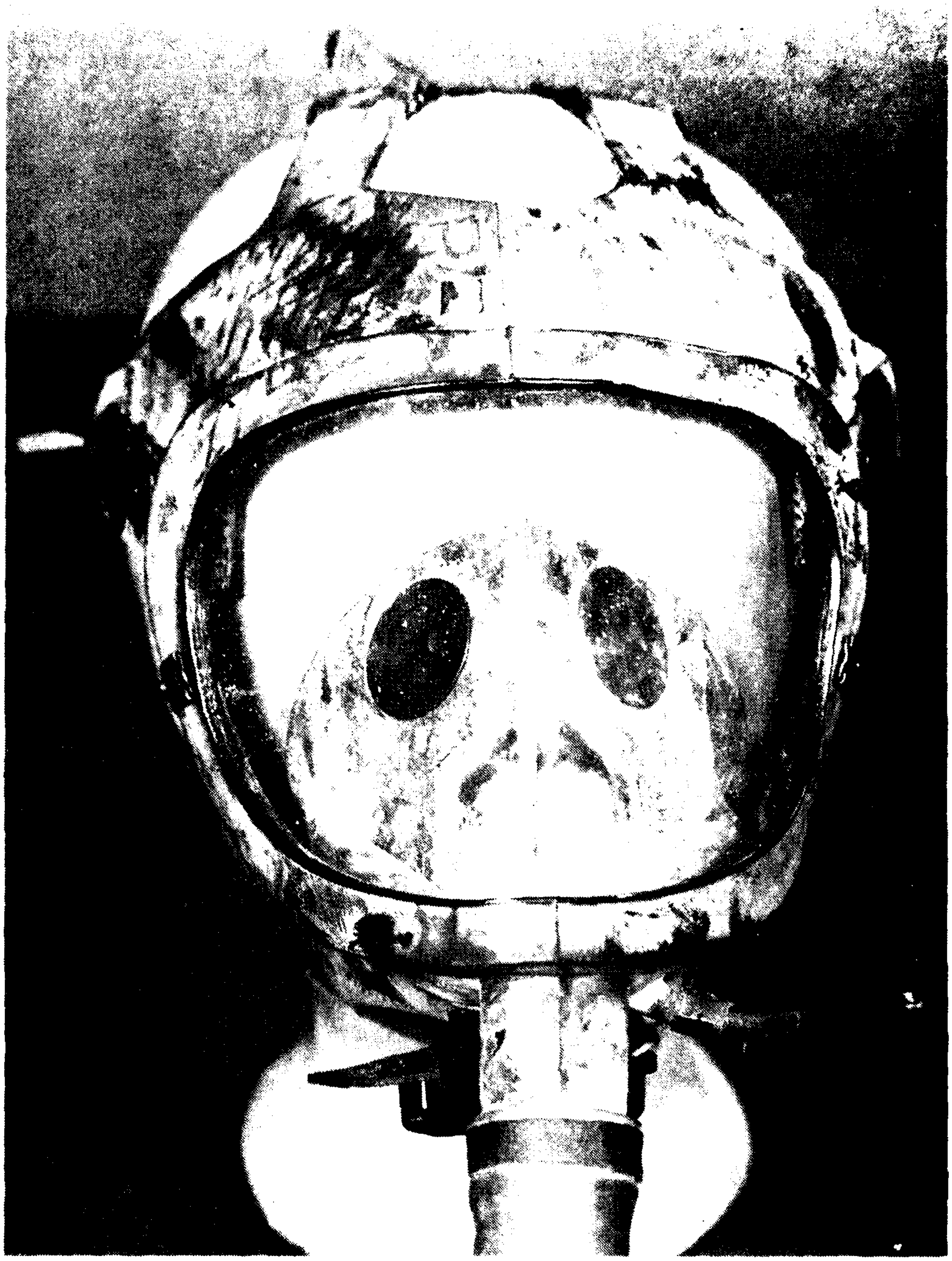


Figure VI-2. Front View of Protective Tank (T-45) Mask Covered with a Light Yellow Material. The Original Color of the Mask Was Black.

Figure VI-3. Front View of Protective Tank (T-93) Mask Covered with a White Chalky Material.

McIntyre, Zylstra (1974), of Dugway Proving Ground performed an environmental surveillance test on the CBR-M19 sampling and analyzing kit from June 1970 to December 1973 at the Yuma, Edgewood Arsenal, Fort Greely and Fort Sherman test sites. The purpose of the test was to determine the effects of long-term environmental storage on functional capabilities of the kit. Although the M19 kit components were generally capable of detecting chemical agents after varying periods of environmental storage, two defects attributable to the tropic environment were found: (a) bleaching of the modified Dragendorff paper, and (b) gross leakage of the alcohol tubes and benzene syrettes. This leakage was later corrected at the test site. It was recommended that packaging and design of the modified Dragendorff paper be improved and that correction of the alcohol tube and benzene syrette leakage be verified by further tests.

Shaw (1977) evaluated results of a 5-year surveillance test of Chemical Agent Detector Kits in the humid tropics of the Canal Zone. The kits were stored in a nonair-conditioned warehouse. At periodic intervals, four to five kits were removed from storage, visually inspected, and sent to Dugway Proving Ground for chemical agent testing. Environmental effects of the storage included deterioration of desiccant crayons and liquification of solid reagent after 3 years of storage.

C. GENERAL EQUIPMENT

This section reports test results of optical systems, a camouflage screen tent, POL tanks, brake fluids and a general purpose disinfectant.

Optical Systems

Optical systems frequently exhibit degradation in the humid tropics. Glass used in lenses and other optical elements is relatively soft compared with conventional glass and can be etched by fungal products. The mere growth of fungi on the optical elements of instruments is sufficient to impair the utility of the instrument, even though etching is not involved. The impairment requires the instrument to be opened up and the lenses cleaned in order to restore the optics to the required condition. If etching occurred, but not too deeply, the lenses would have to be repolished. If the etching were deep, a replacement lens would be required. The principal loss is in removing the instrument from service for the time required to open and repair it.

Berk and Teitell (1954) described tests of methods to prevent fungal damage to optical systems. These methods included placing desiccants, volatile fungicides and radioactive materials in the instruments. These were all effective; however, the use of radioactive substances can produce a health hazard. Optical system designers

concluded that the use of either sealed equipment or equipment kept under slight pressure with a dry inert gas solved condensation and corrosion problems as well as preventing fungal damage.

Hilyard (1970) conducted a 6-month tropic storage test of the Supplementary Light Source, AN/VSS-3 from March until September 1970, to determine if the criteria specified for storage of the item could be met in a humid tropic environment. Requirements were that the searchlight not be damaged by operation and storage and that it be fungus and moisture resistant. Monthly microbiological examinations were conducted and each test item was activated for 1 hour after storage. The searchlight and some of its components proved susceptible to fungus, moisture, and corrosion after 6 months of tropic storage. It was recommended that the test items be treated and sealed to improve resistance to such effects, and then subjected to a full 12-month storage test in the humid tropic environment.

Lens deterioration, not from fungus, was found during a tropic test of the Anti-Laser Goggles (Navares and Leary, 1972). Two types of goggles (figure VI-4) were stored in an open-sided, roofed storage shed at an open Pacific test site. The storage phase started during the last month of dry season and continued into the wet season. The goggles were visually inspected monthly for deterioration. After 4 months of continuous storage, type I goggle lenses were covered with a hard film which impaired usability. The substance rendered the goggles unusable after 5 months of storage. A liquid appeared between the lens plates of type II goggles after 4 months of storage. This liquid rendered all goggles unusable by the 6th month. The goggles fogged continuously in use under jungle canopy and frequently when worn in wet-hot climatic conditions in the open. Chemical analysis of the film showed it to be of crystalline material, possibly a coating put on by the manufacturer that might have changed chemically during storage. Efforts to clean the lens surfaces with soap and water, lens paper, and lens cleaning fluid removed varying amounts of the film. The goggles were damaged irreparably and the test was terminated at the end of 6 months. Figure VI-5 shows an unexposed goggle lens and a lens with film still remaining after cleaning.

Tropic storage and performance tests of the AN/PVS-4 Individual-Served Night Vision sights were conducted for a period of 9 months in the Canal Zone. All test items were stored in a CONEX container placed under the jungle canopy, but were removed for a monthly visual inspection and laboratory baseline check to monitor any degradation caused by storage. Once each week, four of the six sights were operated to insure proper functioning of the image intensifier tube. Cleaning and maintenance were performed as necessary.

A deficiency was failure of the sights to be moistureproof. Moisture accumulation was discovered within the eyepiece lens assemblies

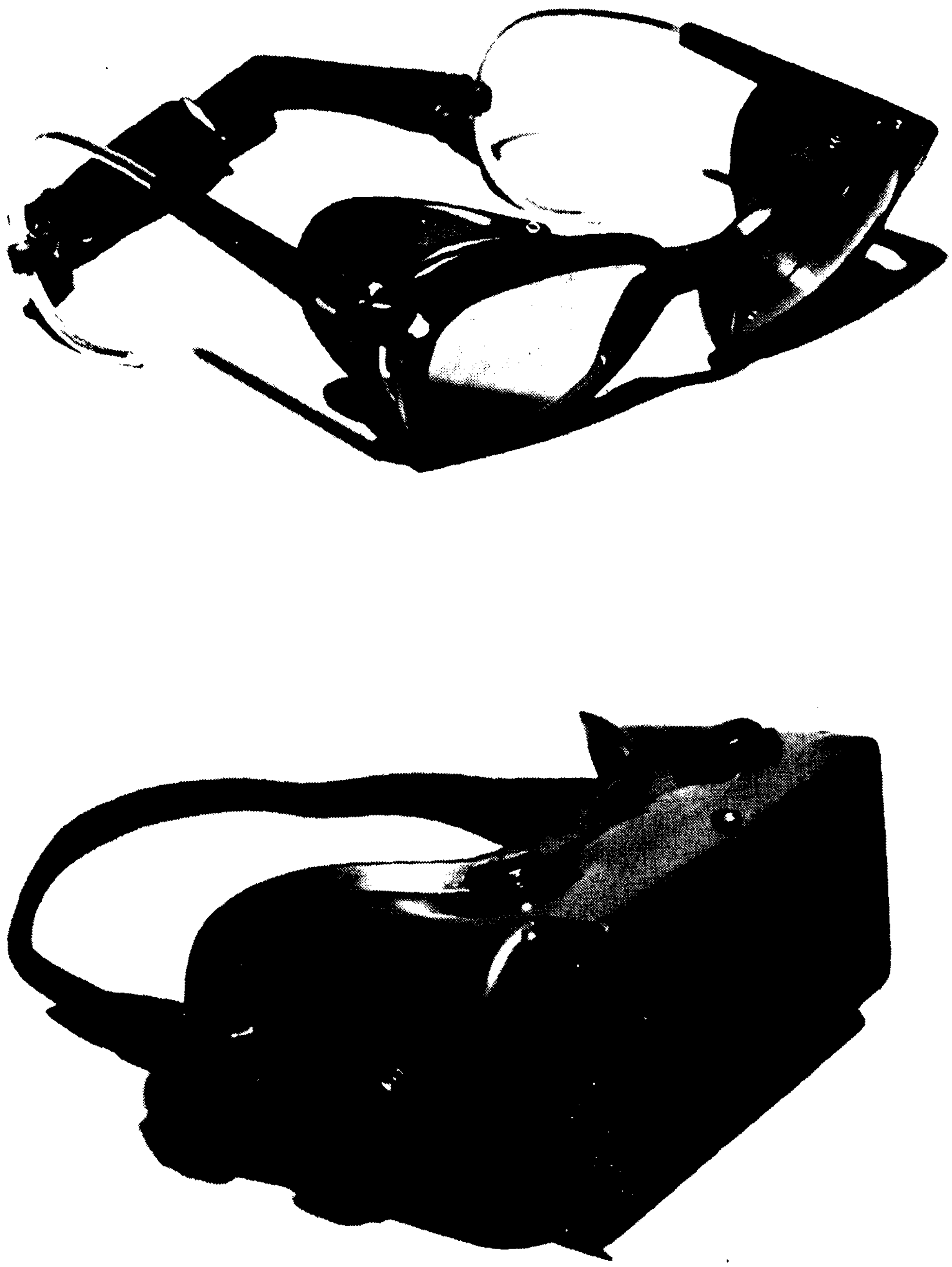


Figure VI-4. Type I and Type II Protective Anti-Laser Goggles.

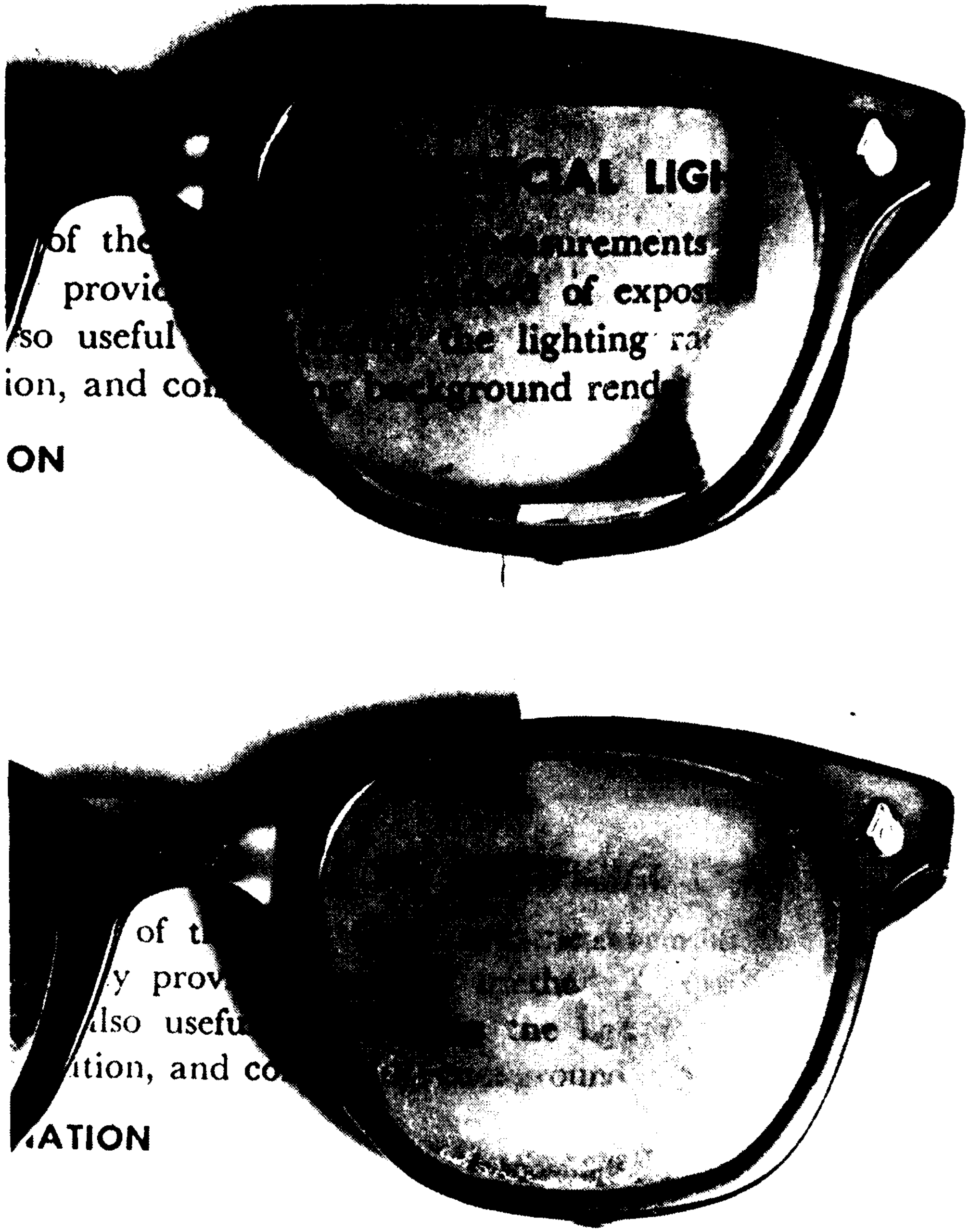


Figure VI-5. Top: Goggle Lens Unexposed to Environment and Free of Film; Bottom: Exposed Goggle Lens with Film Remaining after Cleaning.

during the 8th and 9th months of testing, and seriously impaired operational capability of the test sights. Light fungal growth was observed on sight housing surfaces, rubber eyeshields and the fabric of the carrying bags.

Two-Man Tent

Textiles selected for use in Army materiel need to be proven in the tropics. A report, prepared by McKenney (1973), describes testing of a two-man general purpose tent to determine the adequacy of design for the humid tropics. Two tents were exposed in an open site for 4 months and 9 days, and the remaining four tents were exposed at both open and jungle sites for 3 months. Inadequacies attributed to the environment were as follows:

The tent was not waterproof during heavy rain.

Water condensed on the inside walls of the tent at night.

Field test results showed that the tent material waterproofing factor had deteriorated to an unacceptable level after 3 months of exposure.

The tent sample materials showed a significant strength degradation. The sample exposed 3 months had a tensile strength reduction of 60 percent. The sample exposed continuously for 4 months and 9 days had a tensile strength reduction of 84 percent. This degradation was further illustrated when the two tents (exposed 4 months and 9 days) could not be folded in the field without breaking or tearing the material. Laboratory folding endurance tests showed similar results. New material could be folded over 18,000,000 times before failure, material exposed 3 months failed after being folded approximately 213,000 times, but material exposed 4 months and 9 days failed after only 13 folding cycles. Additional tests with reduced tensile load, on samples exposed 4 months and 9 days indicated that folding failures were attributable to loss in strength rather than in loss of flexibility. Failures in these samples occurred at 6,500,000 folds.

Although the basic design of the tent was comfortable and easy to use, it was judged inadequate for employment in the wet-warm and wet-hot climatic categories. The field life of the tent was less than the required 6 months, and the external fiber glass frame and tent material were not sufficiently durable.

Camouflage Screens

Nevares and Duffield (1972) conducted a 5-month expanded service test of a lightweight radar-transparent and radar-scattering camouflage screening system in the humid tropics. The standard-issue

burlap-garnished twine system had strong moisture retention properties, which seriously degraded radar camouflage performance in the tropics. The screening system was tested for its operational and camouflaging characteristics during two field training exercises under tactical conditions. Eight mobility cycles of controlled erecting and striking were also performed using personnel from tactical units.

It was found that while screening offered an improvement over the standard system, there were deficiencies to be corrected before it could be considered suitable for use in the tropics (figures VI-6 and VI-7). McKenney (1974) conducted a development test to verify the corrective actions recommended during the expanded service test. The following modifications were tested and found acceptable:

Problem Area	Deficiency	Modification
Steel hog rings for garnish attachment	Protective coating on hog rings kept them from corrosion for 30 days of exposure. Severe corrosion occurred when coating began to peel.	Aluminum hog rings.
Pole collar attachment	Adhesive was not strong enough to hold attachments.	Stronger adhesive.
Batten spreaders	Battens made of reinforced phenolic fabric broke or cracked during initial tests.	Redesigned; made of fiberglass.
Transport Cases	Metal tip on straps corroded; fabric tore and frayed easily.	No metal tip; more durable material.

Conley, et al., (1976) reported results of a 2-year field study of newly developed silicone brake fluids for use in military vehicles under tropic, arctic and desert conditions. Conventional brake fluids are hygroscopic and may pick up as much as 15 percent water over a 2-year period in the humid tropics. This water leads to failures caused by corrosion of aluminum and cast iron brake system components. Studies have shown that water can enter the brake system mechanically, through condensation or by permeation of rubber hoses. One water-tolerant and two water-intolerant fluids, plus a conventional fluid, were placed in the brake systems of M151 and M715 cargo vehicles. After a year of operation, the brake systems were torn down and examined. All tropic vehicles using conventional fluids had one or more malfunctions and showed excessive rusting, requiring forceful removal of pistons. No failures occurred during the 2nd year of testing although severe corrosion was evident in cylinders with

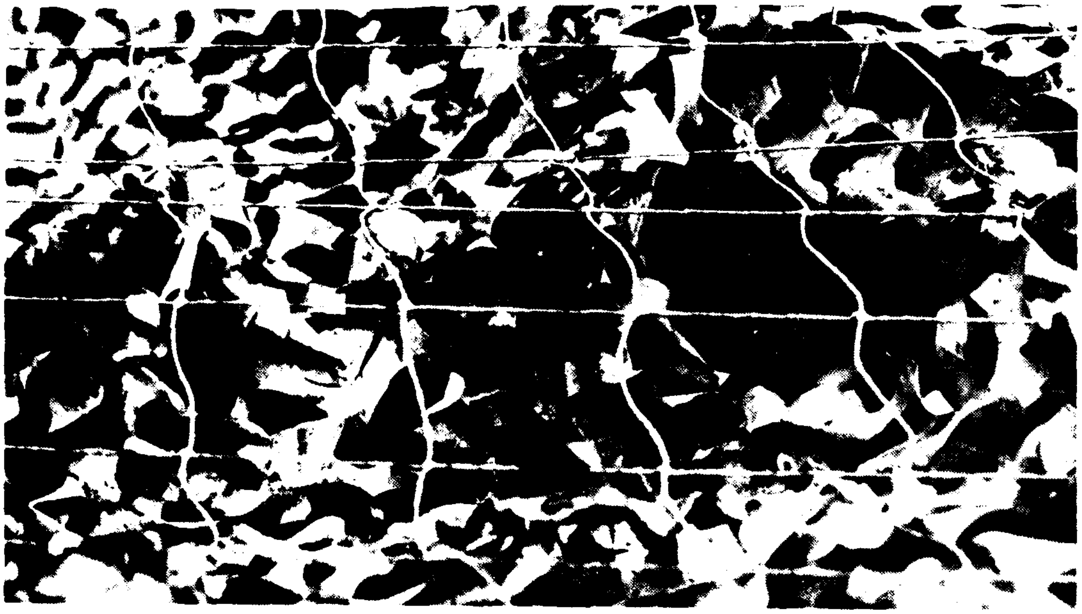


Figure VI-6. Loosely Hanging Garnish Held to Netting by Plastic Staples.

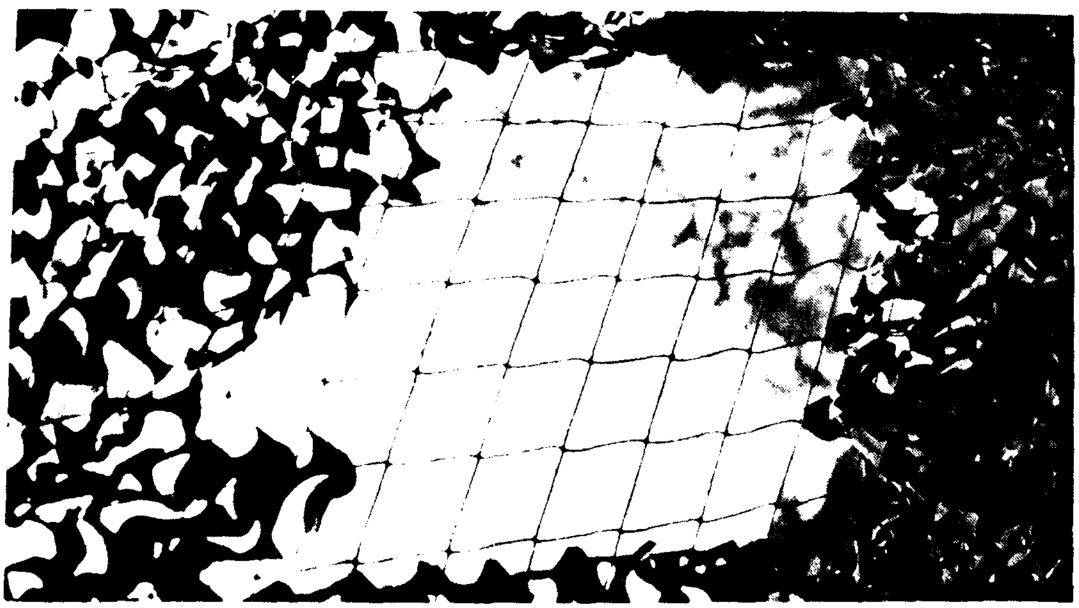


Figure VI-7. Portion of Netting from Which Garnish Had Completely Peeled Away.

conventional fluid. The silicone fluids gave satisfactory operation for the 2-year test period. Water-tolerant fluids caused more staining and corrosion than water-intolerant fluids, but less than conventional fluids. Conclusions were that water-intolerant silicone brake fluids exceeded the performance of conventional brake fluids in all climates, and the tropic climate proved more adverse in terms of failures of hydraulic-mechanical brake systems than either desert or arctic climates. A validated cost study developed jointly between the US Army Mobility Equipment R&D Command and the US Army Tank Automotive Materiel Readiness Command showed that $1.3 million would be saved yearly by converting to the silicone brake fluid.

Disinfectant

Pillion, et al., (1965) of Natick Laboratories, conducted a 5-year storage test of Disinfectant, Germicidal and Fungicide, Phenolic, Dry-Type, Specification MIL-D-51061. The material was developed as a general purpose housekeeping disinfectant. It was selected from a wide variety of candidate compounds as best fulfilling the requirements for a stable, water soluble concentrate which was noncorrosive to metal, nontoxic in normal handling, and exhibited high biological effectiveness in the presence of large amounts of organic material. Objectives of the test were to obtain information on storage stability and performance under adverse climatic conditions. Storage sites were located in Canada (later moved to Alaska--arctic, cold-dry conditions), Massachusetts (temperate, cold-wet conditions), Yuma (desert, hot-dry conditions) and the Canal Zone (tropic, hot-wet conditions).

Throughout the storage period the material of the pouches showed no change except for discoloration of the white kraft paper on some samples stored at Panama. There was a change in color and consistency of the disinfectant powder in all samples except those subjected to arctic exposure. The normal pale tan color darkened progressively to a deep brown. The powder gradually liquified, changing into a dark viscous fluid. Discoloration was observed initially at points along the seams of the pouches, indicating that imperfections in the seal were responsible to some extent for changes. The deterioration was related to temperature and humidity; the Canada/Alaska samples showed no change and the Massachusetts samples only moderate change at the end of 5 years. The samples stored at Panama were completely dark and liquified after 2 years. The samples from Yuma were intermediate, and the contents of individual pouches varied from partial discoloration to complete liquification.

Chemical analysis of the deteriorated samples showed a large drop in phenol concentration which was attributed to the formation of water soluble products, and all but the Yuma samples showed an increase in water content of about 2 percent. Analysis of bactericidal activity showed lower levels than control values, but were sufficient to meet performance requirements.

Collapsible POL Storage Tanks

Prior to 1965, collapsible POL storage tanks were made of nitryl rubber. They were long and narrow, black in color and had an expected service life of no more than 5 years. They were heavy and unsuitable for storage of fuels at low temperatures. Fuel diffusion rate was unsatisfactory; wet spots appeared on the tank fabric and evaporation losses were high. During 1965, development was started on lightweight, urethane-coated fabric tanks (Giordono, 1976).

The 550-barrel capacity collapsible prototype tanks tested in 1973 and 1974 were constructed of a base nylon cloth with a square basketweave, weighing about 9.5 ounces per-square-yard before coating (Giordono, 1975). The nylon cloth was coated on both sides with polyurethane compounds--first with a layer of polyester and then with a layer of polyether. The polyether-type coating was applied thicker on the exterior side of the nylon cloth, while the polyester-type coating was applied thicker on the interior side of the nylon cloth. Overlapping panel seams were formed by bonding the coated fabric with a proprietary adhesive in a press. Seam edges, both inside and outside the tank, were protected by a gummed strip of polyether polyurethane.

During tests, tanks were filled, emptied, and folded according to a set schedule until the test reached its scheduled termination, or failures caused early termination. Incidents such as appearance of wet spots, pinhole leaks, discoloration, and cracking and peeling of fabric coating gave evidence of deterioration and began to occur immediately. In some cases fabric and seam separations caused failure after only a month of testing. Figures VI-8, VI-9 and VI-10 show typical deterioration effects which appeared throughout the tank testing program in the Canal Zone.

With testing of 10,000-gallon tanks, it was established that diesel fuel was more destructive to tank material. Among design problems encountered were rapid deterioration of the exterior coating, fabric and seam bindings. The tops of tanks were particularly vulnerable where cracks from repeated folding had weakened the exterior coating, allowing solar radiation and rain to degrade fabric and fuel. The tanks failed by splitting lengthwise with such momentum that the tear continued through part of the tank bottom. Although all TECOM installations testing tanks experienced some leakage of fuel along the seams, the tanks had been judged suitable for use under intermediate climatic conditions. It now became obvious that the tanks were unsuitable for use in a tropic climate.

Further testing of 10,000-gallon tanks was begun in 1975 in the Canal Zone (Shaw, 1977). Tanks were constructed of single-ply nylon fabric, coated with petroleum resistant polyurethane, weighing about 7.5 ounces per-square-yard. Upon filling to maximum capacity, the

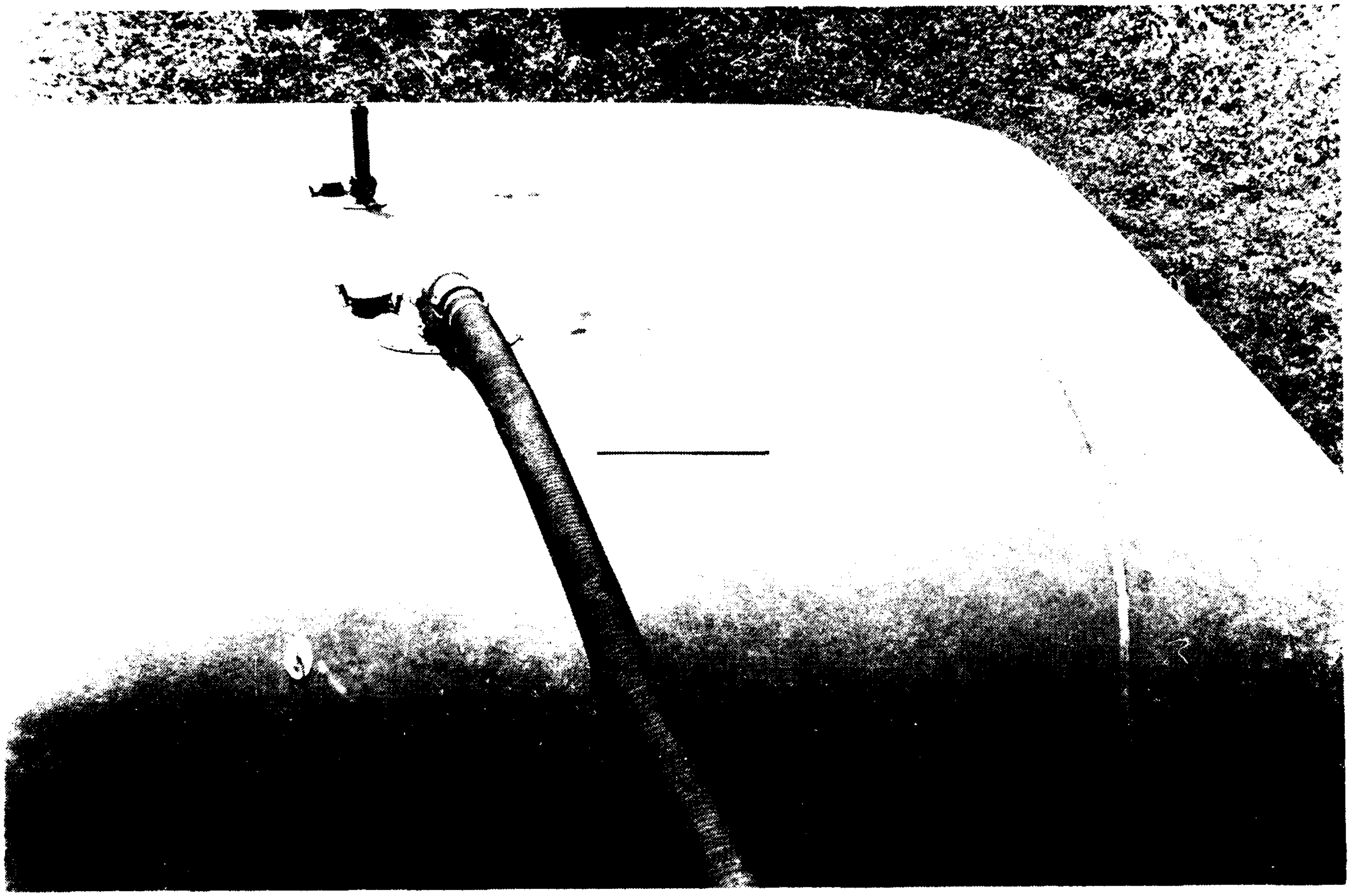


Figure VI-8. Wet Spots, Diesel Fuel Tank, Third Month (Note Repair Clamp).

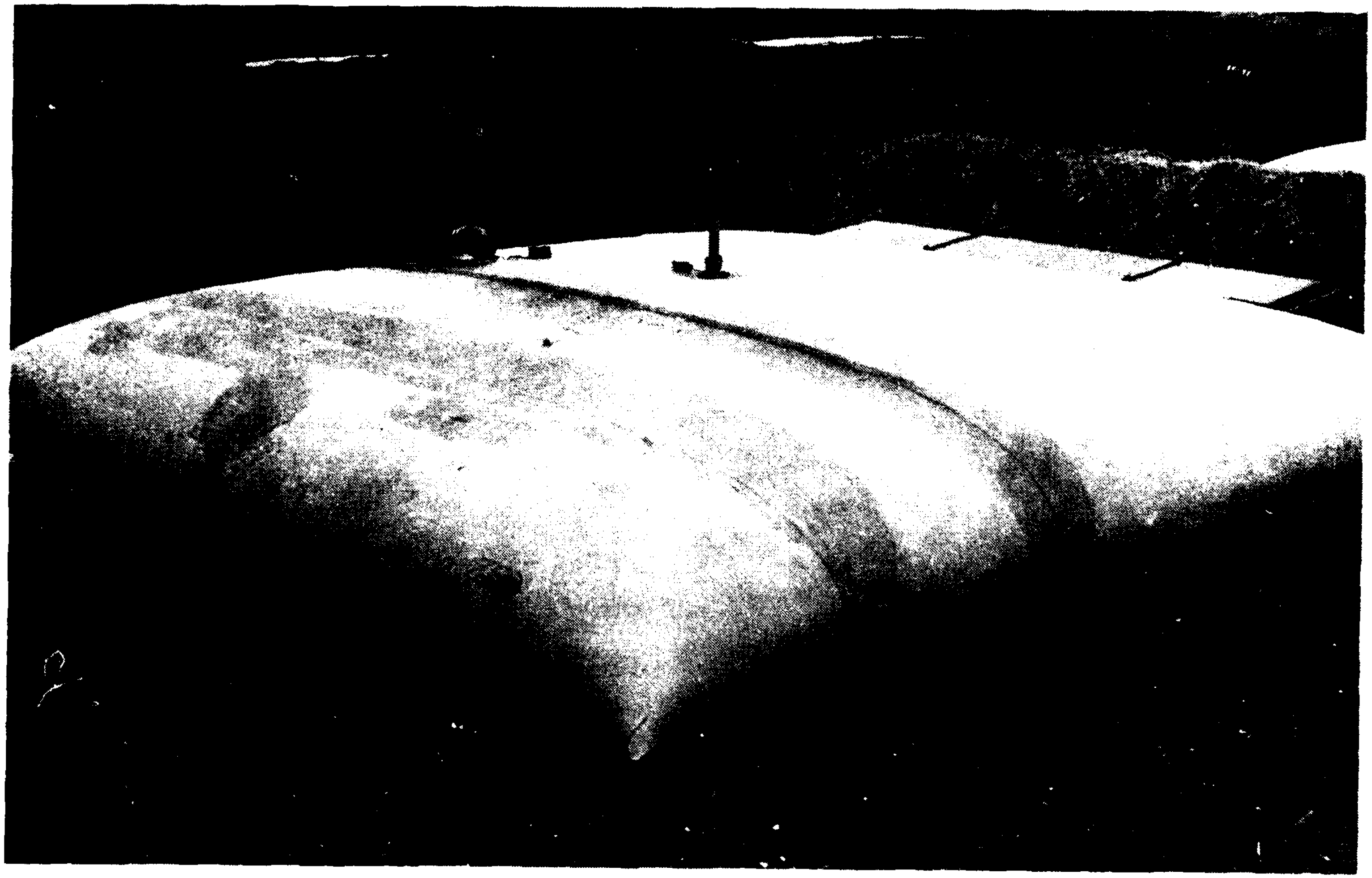


Figure VI-9. Deterioration, Motor Gasoline Tank, 12th Month.

Figure VI-10. Seam Separation, Diesel Fuel Tank, 12th Month.

tank assumed a pillow shape. Diesel fuel and MOGAS were stored in the tanks. Tanks exhibited minor degradation of exterior coatings, massive discoloration and numerous wet spots. Nevertheless, very few pinhole leaks developed and all tanks successfully completed 12 months of testing.

For 12 months from 1976 through 1977, 3,000-gallon tanks were tested using diesel fuel and automotive combat gasoline (Shaw, 1977). All tanks successfully completed testing, exhibiting only minor degradation of the exterior coating and showing wet spots on the tank skin.

For 12 months, 50,000-gallon tanks, filled with diesel fuel and automotive combat fuel, were successfully tested and showed only minor deterioration effects (Shaw, 1977).

For 24 months, 23,100-gallon tanks were tested with diesel fuel (Gunzelman, 1978). These tanks were developed by the United States Army to test the concept that fewer seams in a collapsible fuel storage tank would reduce the probability of seam failures during use in the field. Pinhole leaks appeared and were repaired, the tank coating exhibited minor degradation, wet spots were numerous and tank skins discolored, but both tanks tested successfully completed the storage requirement. This was the first time that tanks had withstood a test of this duration.

For 12 months from 1978 to 1979, 3,000-gallon tanks were tested in pairs using diesel fuel and automotive combat gasoline (Gunzelman, 1979). All tanks successfully completed testing and exhibited only minor degradation of the exterior coating in showing wet spots and air blisters on the tank skin.

D. ELECTRONIC MATERIEL

The humid tropic environment places high stress on electronic equipment. Constant high humidity, diurnal heating and cooling, high rainfall, high saltfall at coastal areas, fungal growth, and insect damage are major contributors to electronic failures. "Field instrumentation" manufactured for use in temperate climates normally does not endure long-term tropic data gathering missions. Laboratory instrumentation can be used in the field for short periods of time if protected from direct rain and maintained in a dry laboratory environment when not in field use. Electronic equipment can be isolated from the natural environment through the use of environmental enclosures or seals. A well designed enclosure with passive or active environmental control is necessary for successful electronics operation in the tropics.

Passive Environmental Control.

The technique of using silica gel canisters within enclosures has been successful at USATTC in the passive control of humidity in enclosed equipment, provided a large initial quantity or regular replenishment of the desiccant is employed. Nevares, et al. (1973), evaluated two standard communications shelters (AN/TCC-69 and AN/TRC-117) fitted with static-free breathing devices. The devices consisted of a large drum fitted with a screen mesh floor and filled with silica gel. The top of the drum was capped with a lid fitted with a 3-inch diameter hose; the hose was connected to a breathing port in the side of the shelter (figure VI-11). As the trapped air inside the shelter expanded during the daytime heating cycle, the air was forced up through the silica gel and escaped through the hose. During evening cooling the incoming air was drawn down through the silica gel bed, giving up its moisture before entering the shelter. Additional silica gel was hung in large nylon mesh socks inside both shelters to further reduce the relative humidity. The two shelters containing electronic communications equipment were sealed in August 1972 and remained sealed for 1 year. Relative humidity and internal and external temperatures were measured and recorded continuously. The relative humidity dropped below 20 percent in approximately 6 hours and remained at this level for the entire year. Specific data on silica gel weights in canisters and socks were:

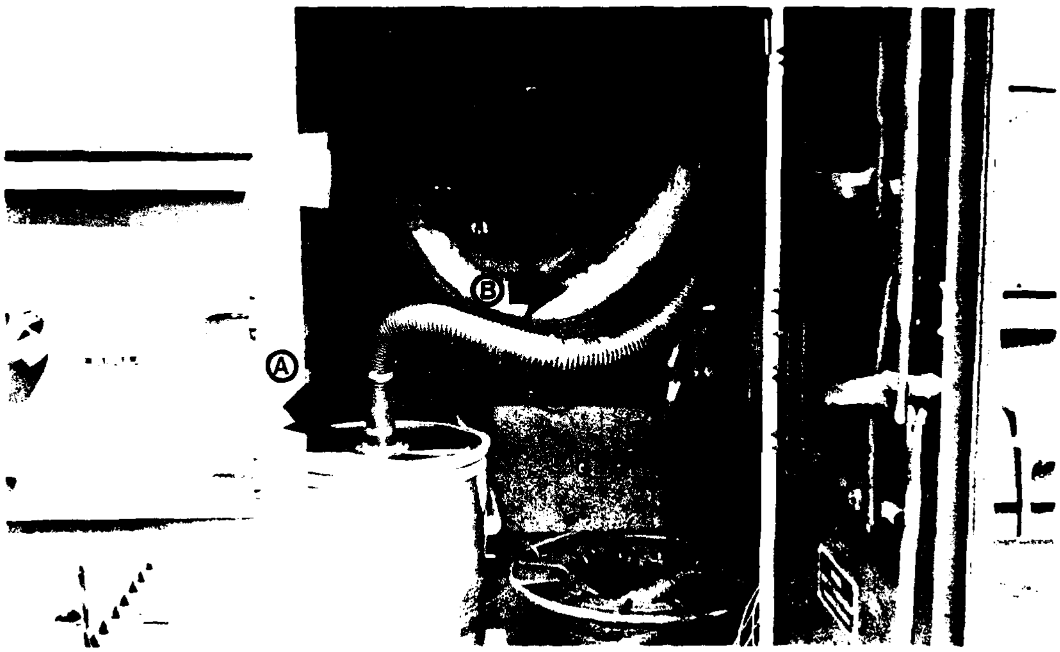


Figure VI-11. AACOMS Shelter Showing (A) Hose Connected from Canister to Breathing Port, and (B) Silica Gel-Filled Mesh Socks.

ACOMS Shelter	Internal Volume (ft^3)	Weight of Silica Gel in Canister (kilograms) Before	After	Weight of Silica Gel in Socks (kilograms) Before	After
AN/TCC-69	203	27.93	30.00	18.22	19.88
AN/TRC-117	501	29.17	32.00	48.00	52.99

Electrical connectors not in the environmental enclosure deserve special attention. The MS series connector with environmental "O" ring seal and gold-plated pins holds up reasonably well in tropic use when the following precautions are taken: (a) if the receptacle mounting flanges are installed on neoprene gaskets or bedded in a polysulfide epoxy rubber; (b) if all plug and socket backshells are potted with a high-quality hard potting; (c) if, before plug-receptacle assembly, both pins and sockets are packed full with a high-quality silicone grease with the plug then forced into the receptacle.

Active Environment Control

Small enclosures can be fitted with pressure relief valves. Dry nitrogen gas, supplied by a small bottle and regulator, is admitted into the enclosure at a low-flow rate. The use of gas to provide a constant, positive pressure inside the instrument case is one of the most effective humidity control techniques available for use in the tropics. When power is accessible, mechanical humidity control is possible through the use of air conditioning, dehumidifiers and heaters.

Insect Damage Control

The best means of preventing insect damage to instrumentation in the tropics is to prevent insect intrusion. The environmental enclosure usually succeeds in this function, but care must be taken to seal or screen all vents and ports. Insects will spin webs or build nests in sensitive areas, sometimes making equipment inoperable in a matter of days unless protected. Termites and cockroaches will remove circuit board potting, scratching and sometimes severing foil paths in the process. Soft pottings seem more susceptible to this type of damage.

Fungal Damage Control

Fungus-susceptible materials should be replaced with inert materials or treated with effective fungicides. Fungicidal varnishes have been used with success on instrumentation at USATTC. A disadvantage is time required for removing and re-spraying at repair and test points of varnish-sprayed circuits. In general, however, the benefits

of fungal varnish outweigh its drawbacks. Fungal protection is not required for instrumentation in an environmentally controlled enclosure.

Electronic Component Testing

Dennison (1968) evaluated the degree and extent of performance degradation of selected passive electronic components exposed in a humid tropic environment. Eighteen different components and several cables, wires, and connectors were exposed for 3 years at two sites--seashore and jungle, and in two modes--energized and unenergized.

Dennison reported that all molded composition resistors, ceramic capacitors, mica capacitors and plastic film capacitors degraded in the humid tropic environment with changes in their performance as a function of time, temperature, and moisture concentration. Moisture uptake was the primary degrading factor that contributed to changes in the basic electrical characteristics of the exposed components. For example, more than 60 percent of three types of ceramic capacitors exceeded degradation limits because of moisture uptake. The average capacitance value of one type increased more than 50 percent.

Total failure of silver-plated BNC-type cable connectors was observed after 3 years of exposure to the corrosive seashore salt spray environment; whereas the U-219()/U aluminum 26-pair Hermaphrodite telephone cable connector, treated with MIL-14072 Finish No. E-561 (Alumilite 225 or equal) hard coat, exhibited no functional deterioration after 18 months of tropic exposure. Telephone field cables and wires (WD-1 and WF-16) were degraded by the stress of moisture and direct sunlight at the shore site, and failed completely because of rodent attack at the jungle site. Gnawed spots were observed approximately every 100 yards on one of the wire samples at the jungle site.

Dennison concluded that the rate of degradation in component performance was a function of a combination of parameters; namely, the rate of moisture absorption, surface moisture and deposited salt concentration, the extent and mechanisms of the moisture reaction with the materials of each component, the impedance of the components, and the extent of miscellaneous stress factors such as contaminants and electrical potential.

Lascaro (1972) evaluated the corrosion resistance of the above exposed electronic components. He reported that the electronic components exposed in the jungle began to show significant corrosion in 3 years, while those exposed at the seashore showed significant corrosion in 2 years. Significant failure mechanisms observed were (a) lead wire corrosion via pinhole or anodic corrosion processes, (b) end seal migration of corrosion productions, (c) plastic erosion because

of salt and moisture attack, (d) element corrosion because of moisture ingress, (e) surface and plastic degradation from fungal growth, (f) electrolytic corrosion because of galvanic couples, (g) solder corrosion because of flux contaminants, (h) silver migration through porous or filled plastic insulation, and (i) case corrosion caused by poor finishes. Of these failure mechanisms, lead wire corrosion leading to open-lead wire failures was the most severe. Recommended corrosion-preventive techniques are presented in the report and by Lascaro (1970).

The testing of plastic encapsulated devices (PED), transistors and integrated circuits, has been conducted continuously in the Canal Zone since 1970 by the US Army Electronics R&D Command. Over 175 million device-hours have been accumulated on 7,000 devices. The objectives of the test program are to determine failure modes and mechanisms associated with PED use in a humid tropic environment; and to develop failure rate data which could be used, along with short-term laboratory test data, to determine acceleration factors for laboratory tests. Devices were tested with and without bias to determine effects of bias and to accumulate storage reliability data. Hermetically sealed devices were included for comparison. Testing was performed in a tropic moist forest, under a dense canopy and at an open site near the Caribbean Sea. The salt fall rate at the open coastal site is extremely high (nominally 507 mg $Cl/m^2/day$) and was used to determine the effect of NaCl on the reliability performance of the devices. The devices were either soldered to printed circuit boards or inserted into sockets mounted on the boards. The boards were housed in an inclosure to prevent rain from falling directly on them.

Hakim and Schauer (1978) have reported the following test results/conclusions:

Ceramic dual-in-line packages (DIP) are superior to most plastic packages; however, devices fabricated with trimetal interconnection metallization and an epoxy novolac encaposulant can be as effective as ceramic-DIPs.

Hermetic flat packs are poorer than most plastic packages.

Silicone encapsulated devices are usually the poorest performers. In general, this can be attributed to silicone's inability to prevent NaCl penetration.

Devices tested in the storage condition (without bias applied) have, in some cases, poorer results than their equivalents which have been biased. This can be attributed to reduction of the relative humidity at the chip surface because of the higher temperature produced by the power dissipation of the device.

Nearly all device failure rates were either decreasing or constant over the exposure period. Devices which had rapidly increasing failure rates, indicating progressive deterioration, included hermetic as well as plastic encapsulated devices.

The predominant failure mechanism for plastic devices using aluminum metalization systems on the silicone die was corrosion at the wire bonding pad.

E. MUNITIONS

The high humidity prevalent in the Panama Canal Zone can adversely affect guns and rifles that are not properly serviced. The common procedure in determining the effects of exposure on ordnance items in a tropic environment is to examine the test item visually and then fire it in order to measure and evaluate ballistic performance. Firings have shown that the tropic environment with its high humidity, heavy rainfall and intense solar radiation contributes to the degradation of munition items.

Troops of the 193d Infantry Brigade (Canal Zone) found that the M92 mount traversing assembly of several 106mm recoilless rifles was malfunctioning. The weapons could be traversed but the lock would not engage. The failure was caused by lubricating grease which had absorbed water and hardened. This problem was corrected by periodic servicing of the mounts.

M117AE2 General Purpose Bomb

The 750-pound M117AE2 General Purpose Bomb containing Minol-2 explosive filler underwent a tropic storage/surveillance test at USATTC (Gidley, 1970). The bombs were stored in an open area and inspected once a week. At the end of the storage period, 20 percent of the bombs exhibited various degrees of exudation. Chemical analysis showed this exudation to be explosive in only one case. USATTC concluded that, as the storage period increases, greater numbers of bombs exhibit exudation and that the rate increases with higher temperatures. Recommendations were made that longer storage periods be tried to see if bomb performance would be affected. Suggestions were also made that the bombs be stored under a protective cover to reduce the effects of direct sun rays on the metal casings, or that the casings be treated with a suitable solar reflective external coating.

AMATEX-Filled Artillery Rounds

Tests conducted on Amatex-filled artillery rounds proved to be an excellent example of the discrepancies that can exist between chamber and natural environment tests. In one case, the chamber heat tests proved too severe and indicated a serious problem in exudation of TNT through the fuse well of the rounds; tests conducted in the humid

tropics showed that no problem existed. In all other cases, chamber tests were not severe enough and failed to uncover a problem found in tests conducted in the natural environment. These discrepancies were caused because temperature-humidity criteria used as guidelines to conduct the simulated chamber tests did not simulate conditions typical of humid tropic regions of the world, and CONUS developers directed that storage configuration of the munitions be modified to permit observation of the expected exudation.

In the natural tropic tests, munitions were stored in an open area as shown in figure VI-12. Storage in this horizontal mode was designed to expose the munitions to maximum heating effects from solar radiation, and hence maximum volumetric expansion of the Amatex fill. Lifting lugs normally inserted in the fuse wells were removed and replaced with a plastic cup (figure VI-13). Use of this storage mode resulted in the following problems:

Exudation was noted as shown in figure VI-14. However, chemical analysis of the exudate revealed that it was composed primarily of ammonium nitrate and contained no TNT. TNT did not exude during chamber tests. This situation occurred because TNT does not liquefy until it reaches 155°F (68°C). In the humid tropics the maximum skin temperature measured was approximately 120°F (49°C)--not high enough to convert the TNT used in the Amatex fill from its normally solid state to a liquid state. Temperatures used in the simulated chamber tests exceeded 155°F (68°C) and thereby caused TNT to liquify and be exuded. In this case the chamber tests were too severe to simulate humid tropic exposure.

The plastic cup did not provide an airtight seal of the fuse well. Diurnal cycling of the temperature and humidity resulted in moisture condensation between the cup and the interior walls of the fuse well. The ammonium nitrate exudate, in the presence of moisture, reacted with the cadmium material to produce corrosion. Similar results were not obtained in the chamber tests because temperature and humidity were not cycled as in the tropics--the parameters were merely raised to their upper limits and held at these values for extended periods of time. As a result there was no "breathing" in and out (caused by alternate heating and cooling) of air trapped between the plastic cup and the interior of the fuse well, and hence no condensation of moisture. Without moisture there is no reaction between ammonium nitrate and cadmium. Because cadmium salts are highly toxic, their presence is a potential health hazard to personnel handling the rounds. In this instance chamber tests were not severe enough.

These test examples emphasize the care that development design engineers must exercise in the use of chamber tests to simulate tests in the natural environment.

Figure VI-12. Amatex-Filled Artillery Rounds in Horizontal Exposure Mode in Tropic Storage.

Figure VI-13. Amatex-Filled Munitions Showing Standard Lifting Lug in Fuse Well, and Plastic Cup Used to Replace Lug in Storage.

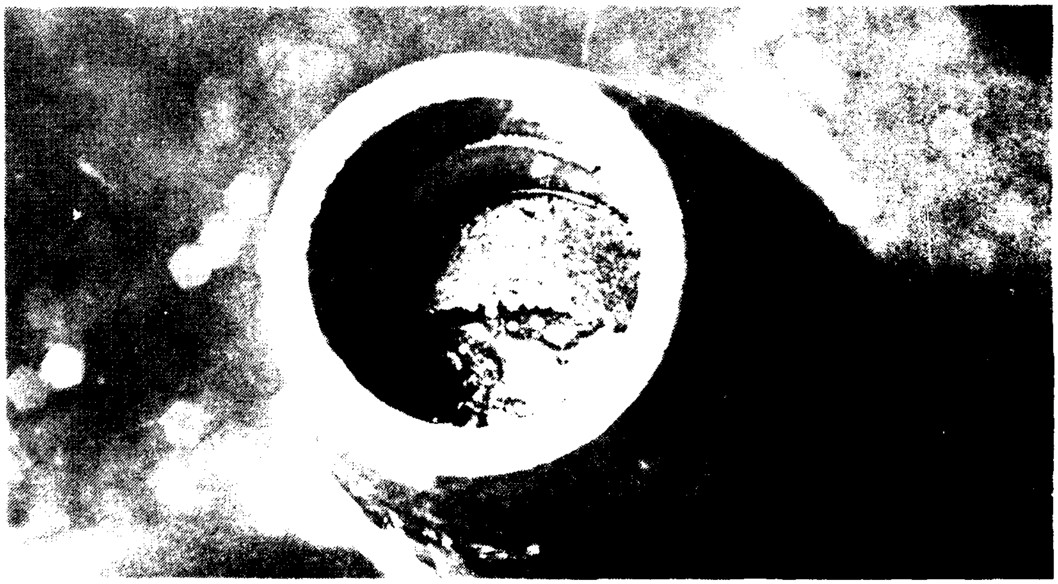


Figure VI-14. Exudation Which Occurred in Amatex-Filled Round After Tropic Exposure.

M18 Smoke Grenade

A 5-year environmental surveillance test of the colored M18 smoke grenade was conducted at Fort Greely (arctic), Yuma (desert), Edgewood Arsenal (temperate) and USATTC (tropic) to determine the effects of long-term environmental storage (Zylstra, 1973). Eight cyclic tests were conducted during the 5-year period. For each cycle, 32 grenades of each color (red, yellow, green and violet) were visually inspected and then functioned to determine the fuze delay, ignition lag, burning times, and grenade movement during functioning, as well as the visibility of the smoke clouds from a 2-mile observation post. Testing showed that the burning, fuze delay and ignition lag, times generally remained within the desired limits, except for the burning times of red grenades during the last firing cycle. These grenades were stored at the Fort Gulick Ammunition Supply Point. Burning times increased for green grenades at the desert site and for red grenades at both the temperate and tropic sites. The clouds produced were generally visible at 2 miles, but during the tropic phase the green and yellow grenades had shorter visibility distances than did the violet and red because of the green-yellow background of the vegetation. During functioning, some red grenades experienced separation of lateral seams and smoke emission from the seams and fuze well. Black, molten filler exuded from the smoke emission holes of the red grenades and tended to interfere with smoke production. This occurred with a total of 16 red grenades in cycles 2 through 8 of tropic testing. After further testing, conclusions were that the M18 grenade can be subjected to 5 years of environmental storage and remain serviceable, even though extended storage of the red grenades in a humid tropic environment will increase their burning times (Greene, 1979).

152mm Cartridge Cases

Williams (1971) conducted a tropic evaluation of 152mm Combustible Cartridge Case Ammunition to judge the performance of XM205 cartridge case. After only 30 days of storage in the humid tropics, the XM205 combustible cases left a smoking residue in the weapon when fired in 35 percent of the rounds tested. Every round left small black particles of non-burning residue that completely covered the breech and breech face. Burning residue was left by 167 rounds. The residue was so intense that each time a total of 50 to 70 rounds had been fired, the breech could not be opened or closed with the remote fire control unit. As a result of these tests, it was concluded that the desirability of using the XM205 high density combustible cartridge cases on all 152mm cartridges needed to be reviewed.

James (1975) conducted a product improvement test of 152mm Combustible Cartridge Cases, M205E1, to determine effectiveness of the two-part coating treatment system in maintaining the interior ballistic level during tropic exposure and in protecting the cartridge

case against fungal attack. Testing consisted of a 6-month environmental storage with firings of selected numbers of rounds after exposure periods of 30, 60, 90, and 180 days. Observations and data were recorded on velocity, chamber pressure and occurrence of residue. For a comparison base, control rounds were fired under the same conditions. Conclusions were that velocity did not differ significantly between ammunition rounds in either the control group or the test group; open covered tropic storage did affect the mean muzzle velocity of the test ammuniton; smoldering residue produced in 6.5 percent of the test ammunition rounds fired did not appear to be linked to exposure time or mode of exposure.

Propellants

Moisture and solvents are considered to be volatiles in solid propellants. These volatiles have a marked effect on the propellant combustion and, consequently, on their interior ballistics. Baer and Bryson (1961) of the US Army Ballistics Research Laboratories have computed the effects of varying amounts of water and ethyl alcohol (solvent) on flame temperature, force and gas volume decrease for the M1 propellant. Lowered pressures and velocities, which produced shorter ranges, were found when moisture levels increased, while higher pressure and velocities and longer ranges resulted when volatiles were lost. Moisture can be gained or lost depending upon environment but solvent, once lost, cannot be regained. Propellants come from the production line with measurable amounts of both water and solvent. Environmentally induced changes in moisture and solvent content can significantly affect munition performance. By controlling the temperature and specific humidity, the moisture migration can be accelerated relative to a set of known conditions.

Hendricksen (1973), of the Materiel Testing Directorate, Aberdeen Proving Ground, conducted a special study of accelerated environmental tests of munitions to simulate extended field deployment. Munition performance data from existing literature were compiled to determine areas in which APG was deficient in predicting long-term environmental effects affecting munitions degradation. APG concluded that it was impossible to determine deficiencies in predicting such effects because of lack of identified degradation mechanisms of ammunition stored in the field. They found the greatest success in employing accelerated tests to artificially age propellants. Such aging can be achieved with temperatures up to 176°F (80°C). They concluded that detailed testing of munitions at APG and Panama was necessary to identify failure mechanisms and degradation rates. It was recommended that the use of applicable test procedures and MIL-Standards be continued for Army munitions testing until sufficient data were accumulated to justify changing procedures.

Ross (1974), of US Army Frankford Arsenal, used test chambers to evaluate the susceptibility to fungi of organic materials used in the

propelling charges of two types of 60mm mortar cartridges, the M49A4E1 and M49A4. The laboratory evaluation was designed to complement results of a tropic chamber test of intact cartridges and performed as part of environmental testing of the developmental 60mm M49A4E1. In the tropic chamber tests, propelling charges of 81mm M374A2E1 cartridges supported fungal growth. In the laboratory studies, the organic components of the propelling charges of 60mm M49A4E1 and M49A4 cartridges were inoculated with a mixed fungal spore suspension and incubated on a mineral-salts agar medium. A medium amount of fungal growth developed on the intact propelling charge of the M49A4E1 cartridge. The celluloid plastic covering of the propellant increment delaminated during incubation in the agar test. The cotton cloth of the increment, and the propellant-containing increment supported heavy fungal growth. The nitrocellulose, plastic and the M10 propellant supported only traces of fungal growth. Failure of the adhesive seal of the celluloid plastic cover caused moisture to enter allowing fungus to develop on the susceptible propellant increment. It was suspected that the adhesive used to bond the plastic cover served as a source of organic nutrient for fungal growth. The intact propelling charge of the M49A4 cartridge was not found susceptible to fungal attack. The M8 propellant, because of nitroglycerin content, was found inhibitory to fungal growth in a test for fungal inhibition on a sucrose-containing medium. Frankford Arsenal recommended that the adhesive, currently used to bond the plastic cover to the container to form the outer part of the propelling charge M49A4E1, be replaced by adhesive not affected by either moisture or fungi.

M64 Demolition Device

Gilroy (1965) tested the XM64 Demolition Device, designed to initiate a demolition charge upon receipt of an acoustical signal emitted by another charge detonated within a prescribed distance. There is a 10-minute delay arming feature. Sixteen devices were tested for arming delay, 16 for functioning after extended emplacement in an armed condition, and four were fired for confirmation. Results indicated that functioning was critically affected by the position of the large acoustic diaphragm. If the diaphragm was in a face-up position during heavy rain, raindrops prematurely functioned the test item. If the diaphragm was perpendicular to the source of the blast or on the side of the firing device away from the sound source, there was a good chance of malfunction.

XM122 Demolition Firing Device

James, et al. (1976), conducted a Development Test II of the XM122 Demolition Firing Device. This system operated by transmissions of coded radio signals, was developed to allow demolition personnel to detonate explosives from remote concealed positions up to 1 km from the detonation site. Tropic performance tests were conducted prior to

placement in tropic storage after 60, 120, and 180 days in storage. A total of 51 missions resulted in 13 recorded failures, 11 of which were attributed to propagation loss. During operations, it was found that the XM122 could not be operated reliably without information on landmass obstructions and vegetation between the transmitter and receiver sites. Line of site was the most reliable mode of operation. Two equipment failures were attributed to effects of exposure to rain and jungle storage.

F. PACKAGING AND CONTAINERS

Packaging of items destined for storage and eventual use by US troops in the tropics is of crucial importance. Materials used will be exposed to many environmentally-induced degrading factors, and packaging that serves in a dry or cold climate may deteriorate rapidly in the tropics. Cardboard and corrugated cartons have moisture content that make them unusable as padding or filling in airtight casings containing metal products. Satisfactory liners are frequently made of double sulfite or sulfate paper, sandwiching a bituminous layer of tar paper, or parafinned or oiled paper. To make these liners humidity-proof, they are sealed with zinc or tin strips. Certain woods withstand tropic weathering better than others, but all are treated with water and insect repellants.

Field storage of items, with ground contact and only a top covering, are subject to fast degradation of packaging. Coatings of thermoplastics such as polyethylene and polyvinyl chloride are excellent waterproofing materials. Aluminum foil placed between a stored item and its packing or container acts as a noncorrosive barrier. Laminated aluminum sealed with a thermoplastic or fabric strip is also a successful moisture barrier. Often, drying agents are added but the packaging must be moisture-tight or water will collect by a process called "breathing" and eventually overcome the capacity of the drying agent to function. Some materials used as sealants are waterproof but still allow air, and thus water vapor, to enter. Packaging must be tailored to suit the item's susceptibility to different forms of degradation and its expected usage. Much testing has been done in Panama to develop cost effectiveness and efficiency in working toward this goal.

Case Liners

Dieruf and Fahey (1959) summarized results from four annual examinations of case liners and contents in wooden shipping containers. Four locations (Yuma, Arizona; Fort Churchill, Canada; Madison, Wisconsin; Panama Canal Zone) were used for exposures, and liners, contents and boxes were examined for rupture, corrosion, warping, and general deterioration. Two liners were composed of different constructions of polyethylene film and kraft paper, and one was a combination of scrim, foil, and polyethylene film. The boxes were constructed of Douglas-fir, red oak, and southern yellow pine pretreated

with a preservative, while one box was of untreated southern yellow pine. Of the four sites, Panama's high temperature and moisture had the most detrimental effects on boxes, liners, and contents.

It was concluded that at all sites the scrim, foil and polyethylene film liner was superior in protecting metal items. The use of the other two types of liners was recommended only in areas of moderate precipitation or in an arid climate. The Douglas-fir containers gave the best protection to all liners and containers. Treatment of the southern yellow pine box with a water repellant preservative proved effective. It was recommended that the type of wood in wooden shipping containers be chosen with the climate of destination in mind and the expected length of exposure. A water repellant should be added if the destination is a humid climate.

Humidity Controlled Containers

Humidity controlled containers occasionally preserve materiel and goods without added special packaging. Part of the equipment evaluated by the US Army Transportation Board Swamp Fox II operation (1964) included a humidity controlled CONEX box. The first controlled humidity box was evaluated under a the project (Swamp Fox I, 1962) and relied on a free-breather tube to draw interior air across the desiccant to maintain the desired humidity. It was found that initial draw-down to the preselected moisture level was a major problem. The Swamp Fox II operation was to test the suitability of a modified box (a small dynamic dehumidifying unit had been installed) as a transporter of select cargo without special preservation measures or packaging, and to test its fitness as a storage medium in humid climates. Shotguns, carbines, paper stock, radios, typewriters, ammunition and machetes were stored in the box for 2 months. Frequent checks of the contents showed no deterioration in condition caused by mold, rust or fungal attack. Based on the favorable results obtained, it was recommended that further evaluations be made prior to bulk procurement of the item.

In 1970, USATTC conducted a tropic storage test of Static-Free Breathers AN/TRG-111 and AN/TRC-65. The test was terminated after 5 1/2 months because the items showed humidity in excess of 50 percent of the full scale, then rose to 75 percent with readings remaining constant.

Nevares, et al. (1973), conducted a check test of medium capacity assemblages AN/TCC-69 and AN/TRC-117 with one Static-Free Breather (SFB) installed in each. The SFB system consisted of a silica gel-filled canister connected with the outside atmosphere by a hose, several silica gel-filled nylon mesh sleeves suspended inside the shelter, and a humidity indicator. The 12-month tropic storage was to verify the adequacy of the SFB to control humidity in the shelters and

protect electronic equipment, and to determine the suitability of the SFB for use in all standard S-250 and S-280 AACOMS assemblages. The AN/TCC-69 and AN/TRC-117 were sealed at the beginning of the test and exposed in an open area to the tropic environment. During the test, the SFB system humidity indicator became temperature-sensitive and unreliable, but an operation check of the equipment after 1 year of tropic storage showed no change in performance. The SFB system proved adequate in controlling humidity in the shelters and protecting electronic equipment.

Ammunition Packaging

Effective packaging designed to protect ammunition cartridges from environmental effects is still a problem in the tropics. In testing the 152mm M205 and M205E1 cartridge cases, James (1975), found that a neoprene moisture barrier bag with a two-part coating of polyvinyl alcohol and polyvinylidene chloride was not entirely effective in maintaining the interior ballistic level of the ammunition or protecting the cartridge case against fungal attack. Open storage affected mean muzzle velocity of the test ammunition. Smoldering residue produced in the test ammunition rounds fired did not appear to be linked to exposure time or mode.

Weiner (1973) mentions that end caps cracked on plastic containers holding 81mm ammunition used in Vietnam, allowing moisture to enter and dampen the propellant. This caused short rounds and the mortar ammunition could not be used. Fiber container inner packs with wooden box over-packs were substituted for the plastic and gave better protection.

A product improvement test of polyethylene containers for 81mm mortar cartridges was conducted for a year to determine if the containers could provide sufficient protection in a humid tropic environment (USATTC, 1967). For control purposes, the standard fiber container and wooden over-pack was made a part of the test. The container over-pack markings began to fade but remained legible at the completion of the test. Mold spots were observed on the over-packs but did not increase in size or quantity. No insect damage, moisture, fungus or bacteria were observed within the over-pack fiber containers. The polyethylene containers were satisfactory for the proper protection of the cartridges from moisture except for the shortcoming noted that some closure caps failed to provide a hermetic seal. Insect nests and fungus were observed on the exterior of containers but not within.

Dust Control Material

Jennings (1974) conducted an expanded service test of Dust Control Material (DCM) and Liquid Distributor for Dust Control (LDDC) from May 1972 to December 1973. The DCM was not capable of being stored and

transported in the humid tropics in the designed containers. Drums were severely corroded and the scrim cardboard boxes disintegrated after 16 months of storage. The knife in each box of scrim was not usable after 1 year of storage because of severe blade rusting and termite damage in the handle.

Riot Control Agent Packaging

In testing the safety and performance characteristics of the XM47E3 CS riot hand grenade, it was found that packaging of the XM47E3 grenades did not completely protect the munitions when they were immersed in saltwater (Ellenberger, 1974). After 9 months in tropic storage the vapor-proof barrier bag showed evidence of weathering. Recommendations were that the storage configurations of the munitions include the original plywood shipping box, and that packaging include a tape seal around the opening of the styrofoam container for protection in case of accidental immersion in water.

Zylstra (1976) reported results of Surveillance/Environmental Tests of Riot Control Agent CS2 (Bulk) in arctic, desert, temperate and tropic environments from February 1970 to March 1975. The test was to determine the effect of environmental storage on chemical and physical properties of CS2 when packaged in bags inside 55-gallon drums and in plastic bottles packed in wooden boxes, and determine firing characteristics of CS2 packed in plastic bottles and fired from an M3 Disperser. After 5 years of storage and testing, it was determined that: (a) caps on the plastic bottles containing CS2 would not withstand extended storage, and (b) the CS2 stored in bottles met more physical and chemical requirements than the bagged CS2 stored in drums.

It was concluded that the plastic bottle could be used for long-term storage of bulk CS2 after redesign of the bottle's screw cap to prevent its cracking.

Colored Smoke Grenade. Zylstra (1973) conducted a series of environmental tests on the M18 colored Smoke Hand Grenade in temperate, arctic, desert and tropical climates. USATTC tested 64 grenades that had been in storage for 24 months. It was found that grenades packed in metal containers exhibited severe paint blistering while those in fiberboard containers did not. After 60 months of additional storage, paint blistering had greatly increased on the grenades packed in metal containers and all grenade markings were illegible. It was recommended that fiberboard containers replace metal containers.

ABC M24 Mask. Zylstra (1974) reported results of a surveillance/ environmental test of the ABC-M24 Chemical-Biological mask conducted at USATTC, US Army Cold Regions Test Center, Yuma Proving Ground, and US Army Edgewood Arsenal. Testing was conducted over approximately a 5-year period to determine the effects of long-term storage under environmental extremes. Performance did not change significantly during

the 5-year storage at the arctic, desert and temperate sites. The same results were obtained for the masks stored 2 years in the original packing at the tropic site. However, storage of masks with packaging removed at the tropic site resulted in corrosion of metal parts, microbial growth on the fabric carrier, and degradation of the canister gas life.

Chemicals

Improper packaging of chemicals needed to maintain equipment may lead to adverse results in combat situations in the tropics. The modified 600-GPH Airborne Water-Purification Unit was tested during Exercise Swamp Fox II (September and October 1962) to determine the effectiveness of the equipment and its water treatment process in a tropic environment. The 600-GPH unit is a self-contained water purification system with all equipment and supplies necessary for production of drinking water. The unit was operated an average of 11 hours a day for 17 days and no operational problems were encountered. The unit performed satisfactorily and produced a high quality drinking water. Some difficulties experienced during the test were: (a) improper packaging caused the loss of limestone and diatomite used in water purification, because the chemicals were packaged in paper bags that rapidly deteriorated in the rain and dampness of the test environment; and (b) the metal containers used for packaging the calcium hypochlorite corroded in a short time and the chemical was lost. It was recommended that more durable plastic packaging be used.

Barrier Materials

Teitell and Ross (1972) conducted tests of the relative fungus resistance of several barrier materials intended for the fabrication of bags, pouches, and sleeves for packaging Army ammunition items. Barrier materials should be flexible, water-vaporproof, puncture resistant and heat sealable. The four materials tested varied somewhat in composition but all contained organic polymeric materials. Samples were buried in biologically active soil or exposed for 1 year in the humid tropics of the Canal Zone. Losses in tensile strength from the soil burial test were low, indicating resistance of the barriers to microbial attack. The tropic sun exposure severely degraded all barriers. When exposed at outdoor tropic test sites shaded from the sun, specimens conforming to Specification MIL-B-131E lost more strength than specimens of other types of barrier materials.

Teitell and Ross (1973) investigated two types of paperboard cartons used for packaging small arms ammunition for fungus susceptibility. One type was made of plain paperboard, the other polyethylene-coated paperboard. The cartons were tested in laboratory soil burial and exposed at tropic sites in the Canal Zone. In the soil burial test, the presence of the polyethylene coating on the paperboard markedly retarded the loss in mechanical strength because

of the microbial action of the organisms. In open tropic exposure, the polyethylene-coated paperboard delaminated leaving unprotected paperboard which rotted sooner than the paperboard of the plain carton. In a tropic forest, the plain paperboard carton was primarily affected by the soaking rains and fell apart; the polyethylene coated paperboard did not last much longer than the plain paperboard as it was rapidly degraded by microorganisms until only the polyethylene film remained. It was recommended that, if cartons are required to withstand some degree of tropic weathering, they be made of a polyethylene-coated paperboard utilizing a fungus-resistant paperboard as the structural member. Tests showed that mechanical strength could be maintained under these conditions. To control the delamination that occurred in sunlight, it was recommended that suitable dyes or carbon black be incorporated into the polyethylene.

G. MISSILES

Missiles have been tested in the Canal Zone since 1960. Numerous design, operation, and maintenance deficiencies have been found by tropic testing, resulting in concrete benefits to the Army by preventing fielding of the defective items and components. The listing below highlights some of these benefits. A number of the items tested were type-classified and issued to troops without benefit of prior tropic evaluation; hence, costly "fixes" were necessary when the item was later tested in tropic environments. Missiles that were stored in the tropic environment often experienced sigificantly more failures when tested at the proving ground than similar missiles stored in a desert or arctic environment. Inspection of the missiles revealed extensive corrosion of metal surfaces, actuator housings, electrical connectors and internal bearings. Deterioration of components was in some cases so severe after only a short storage that weeks of maintenance and spare parts were required to make the system functionable.

Sheridan Shillelagh Weapon System. Booth (1967) conducted tests at USATTC to determine suitability and reliability in the tropics. Two missiles failed to hit the target when fired in rain. One missile went out of control; two missiles failed to hit target when fired at night at a searchlight-illuminated target. There were nine misses out of 11 missiles fired.

Lance. In 1967 the Lance missile system was tested in the Canal Zone (Lamont, et al., 1971). Mobility over jungle tracts was limited, moisture-related problems occurred with electronic components and the sighting device was found to be unstable.

Subroc. Vickers (1968), of Naval Ordance Laboratory. conducted tests in which one inert Subroc missile and three Subroc component containers were subjected to a 1-year exposure in a marine-subtropic environment in Florida to determine their susceptibility to adverse storage conditions. The missile and containers were instrumented with

temperature, humidity and pressure transducers to record environmental measurements. No significant degradation of the Subroc missile occurred as a result of storage. Component containers maintained their leak-tight integrity throughout the entire exposure period. Rusting occurred on all steel containers.

Nike-Hercules. From 1959 to 1962, XM30 rocket motors for the Nike-Hercules missile system were stored for various periods of time at USATTC to determine aging and climatic effects on their performance (Massarotti and Peace, 1962). The motors were shipped to Redstone Arsenal after each storage period, conditioned at 0^oF for 7 days, and statically test fired. The motors met all acceptance requirements except that of the ignition delay time which is specified to be not more than .205 seconds when conditioned at 0^oF. The action time of the motors exceeded the effective burning time by more than 2 seconds, but these deficiencies were found not only for motors stored in the Canal Zone but also for those stored at Yuma, Arizona; Thule, Greenland; and Aberdeen Proving Ground, Maryland.

AGM22B Missiles. Kowalczyk (1974) of US Army Materiel Systems Analysis Agency reported on Air-to-Ground, AGM22B missiles which had been in open storage in the Canal Zone and Alaska and in igloo storage at Letterkenny Army Depot. Each year, for 5 years, five missiles were sent to Aberdeen Proving Ground where they were test fired and given component analysis and evaluation. Electrical checkout tests on the missiles stored for 4 years at the Tropic Test Center revealed that two missiles had open gyro and rocket motor igniter circuits and could not have been successfully test fired. Missiles stored in the Canal Zone had an average resistance reading 3.362 for Rocket Motor Booster Ingiter/Flare circuit. Missiles had average readings of 2.028 in arctic storage and 2.106 in temperate storage for the same circuitry. Examination for cause of open circuitry in tropically stored missiles showed wires broken as a result of long-term corrosion. The corrosive action detected in previous tests (3-year storage) appeared in more missiles with greater severity. Open circuits were found only in the missiles stored in the Canal Zone and it was concluded that prolonged storage in the tropics without the benefit of desiccant degrades missile performance to the point of failure. As storage time increases, corrosion effects become more severe. Further tropic storage was recommended with desiccant in use and periodically changed to see how well the AGM22B might withstand the environment when stored properly in a suitable container.

H. VEHICLES AND AIRCRAFT

In past tests conducted in the Canal Zone, lack of mobility through tropic vegetation and terrain was a recurring problem of tracked or wheeled military vehicles. Major obstacles to off-road mobility included slippery lateritic clay soil, closely spaced tropic trees and thick vegetative undergrowth. In some instances mobility is restricted to a few hundred meters. Excessive grass accumulation in

the suspension system of tracked vehicles, causing the track to be thrown repeatedly from the sprocket, has been observed in grassland mobility trails.

D7 Crawler Tractor. An evaluation was made of a low ground pressure (LGP) D7 Crawler Tractor, which served as a support vehicle in Exercise Swamp Fox (1964), to determine its suitability for tropic and jungle operation. It was transported, then off-loaded at a distance of 17 miles from the Base Camp. The bridges along the road to the Base Camp were too light and narrow to support the tractor. In a first attempt at preparing a bypass, the tractor had to fill in an area and when attempting to cross the fill, sank on one side in water and sticky mud to a depth of more than 3 feet. Recovery of the vehicle was difficult, but once recovered, the tractor completed the trip with only minor difficulties. The tractor was serviced and moved to an area of canopy-covered jungle containing undergrowth and trees up to 5 feet in diameter and 75 to 100 feet high. Roots extended 15 to 20 feet from the base of the tree trunk with dense vines extending from tree to tree. The tractor cleared this 1500- by 500-foot area for a drawbar pull course in about 6 hours. It was decided that problems could be expected if the tractor operated in a more dense canopy-covered jungle.

During operations of the D7 tractor, the overall width and weight appeared to be excessive for the tasks encountered. Also, from observation of all of the vehicles participating in the exercise, it was apparent that a low ground bearing pressure was of utmost importance. A smaller tractor in size, weight and ground bearing pressure would be more suited for use under these conditions.

D7E Tractors. Cappel and Magee (1971) conducted a product improvement test of two D7E tractors with attachments in the humid tropics of Panama from March 1970 to June 1971. Objectives were to compare the performance of a D7E tractor equipped with two modified blades (blades A and B) with the standard blade. Both modified blades outperformed the standard blade during tree-felling operations. However, while windrowing, both had considerably lower production rates than the standard blade. The weight of blade B was more evenly distributed than that of blade A, making the D7E tractor with blade B more agile in mud. Of the three blades tested, blade B achieved the best results in tree-felling in rough terrain, and the standard blade achieved the best results in windrowing in rough terrain.

M113A1 Vehicles. Lamont, et al. (1971), performed an engineer design test to determine Lance Missile system degradation from storage over a 60-day period. This was followed by ground mobility testing of the system in a tropic environment using the XM752 Self-Propelled Launcher, XM688E1 loader-transporter (both are modified M113A1 vehicles), and XM740 towed launcher. The limited Canal Zone storage test yielded minor degradation results that included corrosion of all unfinished metal surfaces, fungus on rubber door seals and cloth seat cushions,

swelling of wood (mobility kit) items from moisture, and high humidity indications in the propulsion unit boat tails. Operational tests included 40 simulated fire missions, and the reaction times were not significantly affected by the tropic environment when compared with temperate zone environment reaction times. Results of 1,000 miles of operation of the vehicles showed inability to operate in dense jungle trails, but satisfactory traversal of swampy areas intermingled with savanna grass terrain. Grass and debris accumulated on the engine intake grill, significantly raising the temperature of the engine coolants. Items such as tail lights, ramp latches, cab and swimming shrouds that extended outside the vehicle structure were often broken or damaged by jungle vegetation. Water accumulated in vehicle final drives. To prevent the tracks clogging with savanna grass, it was necessary to remove the rubber swimming shrouds.

Problems encountered during tropic testing of aircraft include accelerated brake lining wear caused by the abrasive action of mud and sand, heavy amounts of rust on nonaluminum parts and adhesive failures around engine covers and under cab consoles. Microorganism growth in the lubricant of a helicopter can clog the hole in the sight level gauge, giving a full reading when in fact, the gearbox is empty. Such frequent though minor problems have had serious consequences resulting in higher maintenance costs in the tropics than in other areas where the aircraft are used.

F-4AE Aircraft System. Sandstrom (1970) reported on the F-4AE Aircraft system and components which had been operationally tested in the Canal Zone after extended soaks in a high humidity, high temperature environment. The test was conducted by the US Air Force at Howard Air Force Base, Canal Zone, in 1968. Twelve missions were performed for a total of 16.5 hours of flight time. Prior to the environmental exposure test, the aircraft had been subjected to chamber tests at the Climatic Laboratory, Eglin, Air Force Base, in February through May 1968. In the actual environmental tests, the cockpit air-conditioning system was found to be deficient as it had been in the chamber cycle. The system was found inadequate for takeoff, landing, and low level flights with takeoff temperatures of 80°F (27°C) to 90°F (32°C) and humidity ranging from 75 to 91 percent. A water leak found during chamber spray tests in the data link bay was not evident during the tropic test.

UH-1N Helicopter. Ford (1971) conducted tropic tests for the US Air Force of the UH-1N helicopter to determine the effects of corrosion, fungal growth, and water leakage on the aircraft and its subsystems. The aircraft was left in an open unsheltered area for 1 month during the wet season of 1970. Flights were conducted with all installed subsystems activated and with instrumentation recording systems operating continuously throughout each test flight. After each test flight, the aircraft was examined for signs of corrosion, water accumulation, and other climatic effects. Fluid samples were obtained

from various components of the aircraft and microbiologically tested for signs of fungal growth. It was found that after 22 days of testing, corrosion had developed on several exposed engine and flight control components but had not become severe enough to warrant replacement of the parts. Numerous water leaks occured during testing, allowing water to accumulate on cockpit and cargo floors. Results of microbiological inspection of oil and hydraulic fluid samples taken after the 22-day exposure period showed no signs of fungal growth; however, inspection of samples taken 8 days later (the helicopter had hovered over saltwater and had been washed) revealed a yeast-type growth in the 90-degree gearbox. Water entered the gearbox during its washing and initiated fungal growth. It was recommended that the 90-degree gearbox vent have a water shield. Protection against the environment was determined to be satisfactory for the UH-1N in all other respects.

C54 and B-24 Aircraft Components. Components of military aircraft that have been sealed or partially sealed have been found to perform after long-term exposure in desert, arctic and tropic environments. Billet (1967) reported findings on the operational capabilities of electronic parts salvaged from a C-54 cargo-type aircraft which had been in the Panama jungle for 6 years, and a B-24 bomber which had been in the jungle for 24 years. An electric-motor-driven hydraulic pump from the C-54 would not turn over, but when tested separately it reached its normal pressure. Interior parts of the unit showed very little corrosion or deterioration. A fuel flow transmitter was taken from the B-24 aircraft and, although it was covered with corrosion and fungus, was found to be operational. The interior components were also in good condition. Similar studies made on fallen aircraft in the Libyan Desert and Arctic/Greenland icecap showed that the interior of hydraulic cylinders and engine driven pumps were in excellent condition--the units functioned like new after periods up to 23 years of exposure.

SECTION VII. MATERIEL RELIABILITY AND MAINTAINABILITY

A. REALISTIC RELIABILITY AND MAINTAINABILITY REQUIREMENTS

Materiel performance criteria include reliability factors to assure combat effectiveness. The specified reliability requirements necessitate thorough testing under expected use conditions. Since laboratory testing is by nature somewhat artificial, the results are often invalid, conflicting with the failure rates experienced in actual use. High failure rates are frequently manifest during military use because items are not designed for reliability in the environment where they must function. The lack of design for field reliability is well documented. Willoughby (1976) and Marsh (1976) summarize their views on realistic reliability and maintainability requirements:

> Inadequate testing is probably responsible, more than any other factor, for the poor reliability of military procurement.
>
> Figure VII-1 indicates that the ratio of laboratory versus field-demonstrated mean time between failures is greater than 1 for 75 percent, greater than 2 for 55 percent, and greater than 32 for 8 percent of all avionics components.
>
> Lack of design for field reliability has resulted in costly logistic support which could not be provided for some critical systems under combat conditions.
>
> Contractors are motivated to design to the benign reliability test environment rather than the field environment.
>
> For many other systems and equipment, the restriction of testing to the factory or laboratory has resulted in overstating field reliability.
>
> The primary objective of any reliability test program must be the achievement of adequate field reliability rather than laboratory reliability. Therefore, the environmental conditions under which this testing occurs must accurately reflect the operational environment in which the equipment will be operated.

This outline parallels a problem long discussed by tropic testers and DARCOM developers; that is, systems fail in tropic use because they are type-classified without a tropic test, or because a short-run, high-risk test was conducted.

The Tropic Test Center's mission includes the conduct of Development Tests as well as other tests and evaluations, as directed by higher headquarters. Test duration has varied widely for different reasons. In many cases, the duration has been dictated purely by the

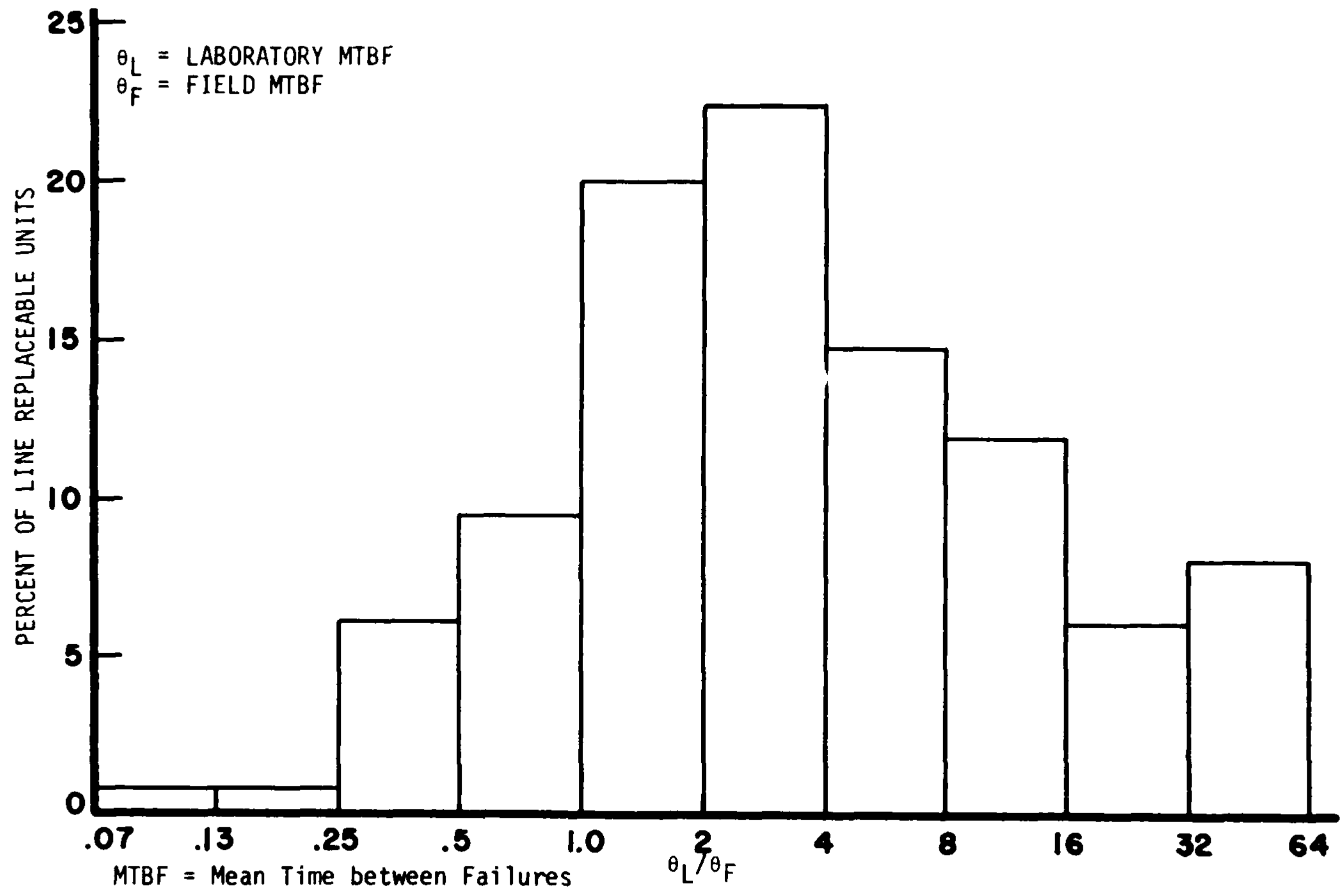


Figure VII-1. Laboratory Versus Field Reliability of Avionics Line Replaceable Units

practical urgency of getting the test item into the next phase of development or deployment. Insufficient attention has been given to getting an adequate environmental soak period or operational, active tropic phase; the only exception being the surveillance type or long-term exposure test, conducted usually as a warranty test after the item has been fielded or to determine probable shelf life.

Tropic testing is relatively time-consuming. The general rule for recommending a 12-month test time is based on several important environmental influences on materiel. These environmental influences are dependent on wet and dry conditions which require 1 year for a full cycle. During this cycle, materiel in use by Army units experiences varying exposures to rainfall, heat stress, solar radiation, microbial penetration, and atmospheric contamination by natural and man-made chemicals. Yet, time is money, and materiel developers have a legitimate requirement to minimize test time and reduce costs.

B. FIELD TESTING METHODOLOGY INVESTIGATION

USATTC conducted a methodology investigation for the benefit of DARCOM commands, DA project managers, and TECOM materiel test directorates whose developmental items required field testing in the tropics (Bryan, et al., 1976). This investigation was designed to help the developer assess the risks involved in tropic tests of varying time increments up to two years. It was hypothesized that, through the collection and analysis of data on operational failure of materiel items in selected commodity areas, it would be possible to assess risks involved for varying tropic test durations. Units of the 193d Infantry Brigade (Canal Zone) were selected as representative combat-ready user units in the tropics. Data were collected on the following items:

- M151A2 1/4-Ton Truck
- M113 Armored Personnel Carrier
- M16A1 Rifles
- AN/PRC77 Radios
- OH58A Helicopter
- MC1-1 Parachutes
- Jungle Boots and Fatigues

Where possible, tropic data were compared with available worldwide data as shown in examples at tables VII-1 and VII-2.

Failure trend analysis and reliability and maintainability analysis were accomplished to develop guidelines for test lengths. Recommended test lengths were based on tropic failure trends developed for major components. Failure trends of critical components were emphasized, and failures of major components were analyzed to determine if the expected times between overhaul were valid for the tropics. The analysis resulted in the following conclusions and recommended tropic Development Test II (DTII) test lengths.

TABLE VII-1. Mean Flight Hours Between Parts Replacement for OH58A Helicopters

Functional Group	Canal Zone Tropics-MTBR (Hours)	Worldwide MTBR (Hours)
OH58A End Item	11.4	13.2
Airframe	70.3	176.8
Power System	47.6	104.0
Transmission and Rotor	36.6	28.0
Hydraulic System	143.9	512.3
Instruments and Panels	105.5	441.0
Electrical System	81.5	168.9
Fuel System	791.3	585.8
Flight Control System	452.1	235.9

TABLE VII-2. Mean Miles Between Parts Replacement for M151A2 1/4-Ton Truck

Part	Tropic (Miles)	Worldwide (Miles)
Engine	5,556	13,410
Fuel System	8,108	25,927
Exhaust System	12,973	59,831
Cooling System	9,725	86,423
Electrical System	1,667	2,454
Transmission	21,621	22,223
Propeller Shaft	16,216	57,616
Brakes	32,432	51,854
M151A2 Truck (End Item)	649	1,277

Short tropic test durations (6 months or less) are technically feasible, providing that higher test risks are acceptable to the Army. Parts replacement data obtained provided guidelines for test length selection for future families of aircraft, and tracked and wheeled vehicles that are evolutionary improvements--not radical new designs.

Relatively long periods are required for failure trends to develop fully on some aircraft and vehicle subsystems. Tests of sufficient duration to allow development of tropic failure trends are classified as low risk tests. Low risk test times resulted on all commodity classes studied.

Static storage or <u>soak periods</u> prior to use cause accelerated tropic operational failures for some items, as evidenced by a comparison of the OH58A tropic service test with the operational maintenance experience. Army vehicles and aircraft deployed in the Panama Canal Zone experience lower usage than in other areas, which tends to accelerate corrosion. Because of low operational usage, there is a correlation between operational failures and test failures which occur as a result of the storage phase.

Tropic failure rates are higher than CONUS failure rates for both vehicles and aircraft. Consequently, Development Test I (DTI) component tests and early confirmatory DTII testing should be done in the tropics as an alternative to temperate zone testing for accelerated results and a rigorous challenge.

Tropic failures were related to particular subsystem components prone to corrosion (bearings, U-joints, switches, electrical contacts, OH58A compressor, engine, rotor blades) and prone to elastomer failure. Therefore, DTI tropic testing of components would minim[illegible] risks and elimate or shorten tropic DTII tests for some hardware systems.

Vehicle operational requirements in Army units in the Canal Zone for the period 1972 to 1974 included a minimum of operations in secondary, cross-country, and off-road modes. Under such mild usage, incidence of tropic failure is expected to be lower than for intensive testing. Thus, the test times recommended in the present report probably overestimate the minimum requirement for an intensive test.

MC 1-1 parachutes experienced few wear-outs because of controlled storage, adequate preventive maintenance, and relatively low usage. The administrative criterion for turn-in is not a measure of durability and restricts realistic short test designs.

AN/PRC77 radios had low failure rates because of relatively low usage and a controlled storage environment. To maximally challenge these items and shorten test time, tropic tests should concentrate on storage modes under ambient environmental and rigorous training conditions.

More objective criteria are needed to determine operational reliability of jungle fatigue uniforms. Intensive testing under heavy field training will increase wear-out rates.

Recommend the following test lengths for tropic DTII testing:

Commodity Class	Test Time (Months)**	Number of Test Items*	Storage (Months)
Aircraft	6 - High Risk	1	3
	9 - Medium Risk	1	4.5
	12 - Low Risk	1	6
Wheeled Vehicles	6 - High Risk	1	3
	9 - Medium Risk	1	4.5
	12 - Low Risk	1	6
Tracked Vehicles	6 - High Risk	1	3
	9 - Medium Risk	1	4.5
	12 - Low Risk	1	6
Clothing	3 - Medium Risk	20	1.5
	6 - Low Risk	20	3
Parachutes	6 - Medium Risk	10	4
	12 - Low Risk	10	9
Radios	6 - Medium Risk	20	6
	9 - Low Risk	20	4
Rifles	6 - Medium Risk	20	6
	9 - Low Risk	20	4

* In situations when only one item is available for storage, test length standards may be adopted on a case-by-case basis, resulting from an examination of the material composing the test system and the storage conditions. One test item was assumed for vehicles and aircraft because normally no more than one vehicle or aircraft is available for a tropic DTII. Moreover, increasing the number of test items to decrease the test length is not desirable because many tropic failures do not appear during the first 6 months of typical Army use in the tropics.

** For aircraft, wheeled vehicles and tracked vehicles there are also operational hour or mileage requirements--see referenced USATTC report.

C. INTENSIVE TROPIC FUNCTION TESTING

Army regulations such as AR 1000-1† require that efforts be made to shorten the materiel acquisition process without sacrificing materiel quality. It was hypothesized that reducing test calendar time while increasing equipment functioning time (intensive function testing) would yield valid tropic reliability and maintainability results for some categories of equipment.

†AR 1000-1, Basic Policies for Systems Acquisitions, 1 April 1978

Army materiel deployed in the tropics normally undergoes some period of storage; therefore, tropic testing has traditionally included a storage phase. Because the storage period represents a significant amount of calendar time, it has been proposed that the storage phase be shortened or eliminated and items be tested at an intensive functioning rate. Since Tropic Test Center has observed materiel failures which occurred in the tropic storage phase, a methodology investigation was conducted to determine whether comparable RAM information could be obtained from different functional modes of testing (Cady, 1978).

Fifteen 1.5-kilowatt AC generators were separated into three groups of five generators each, so that each group could be functioned on a different schedule. The Intensive Function Mode group was operated at a rate of 16 hours per day for 6 months. The Storage Mode Group was operated at a rate of 4 hours per day for 100 operational hours, placed in storage at the test site for 6 months and returned to operation at the same operational rate for the remainder of the year. The Simulated Tactical Use Mode group was functioned at a rate of 4 hours per day for 1 year. The test site selected was a concrete pad in the Fort Clayton General Purpose Test Area in the Canal Zone. The power produced by each generator was consumed by a series of 300-watt bulbs. Every hour the operator varied the power load from 900 to 1500 watts for a 15-second period. Hourly records were kept of the stable voltage and frequency levels and total elapsed operation time. Changes in the normal operational behavior of a generator were used as indicators of a malfunction and repairs were performed. RAM data were generated from reports made for each maintenance action and from the operator's log book.

Mean Time between Failure, a primary measure of test severity, indicated that the Intensive Function Mode was less severe than either the Storage or Simulated Tactical Use Modes.

Mean Time to Repair and Maintenance Ratio for Unscheduled Maintenance actions for Storage and Simulated Tactical Use Modes were about twice as high as those of the Intensive Function Mode.

Detailed examination of unscheduled maintenance actions showed that similar types of malfunctions occurred in all three functional modes, but the distribution of malfunctions differed among the three modes. The malfunctions which occurred in Intensive Function generators generally required less time to repair.

The reliability and maintainability data collected showed that reliability and maintainability estimates made using different functional test profiles differed substantially; therefore, valid reliability and maintainability estimates require that functional test profiles follow mission profiles as closely as possible. Tables VII-3, VII-4, and VII-5 summarize the data collected.

Table VII-3. Summary of Intensive Function Mode Data

Generator Number	Total Test Hrs	Number* Maint Actions	Number Chargeable System Failures	Number* Maint Act per 1000 Hrs	Number Chargeable System Failures per 1000 Hrs	Chargeable System Failure Time (Man-Hrs)	MTBF (Hrs)	MTBMA	Active Maintenance Time*: Unscd (Man-Hrs)	Scd (Man-Hrs)	Total (Man-Hrs)	Unscd Maint Time per 1000 Hrs
1	878.6	6	4	6.8	4.6	3.6	219.7	146.4	3.6	3.0	6.6	4.1
2	2033.0	18	10	8.9	4.9	5.9	203.3	112.9	5.9	6.1	12.0	2.9
3	1867.5	17	10	9.1	5.4	5.7	186.8	109.9	5.7	6.1	11.8	3.1
4	2077.9	10	4	4.8	1.9	3.4	519.5	207.8	3.4	5.1	8.5	1.6
5	2133.1	16	9	7.5	4.2	6.7	237.0	133.3	6.7	4.6	11.3	3.1
Total	8990.1	67	37	-	-	25.3	-	-	25.3	24.9	50.2	-
Mean	1798.0	13.4	7.4	7.5	4.1	5.1	243.0	134.2	5.1	5.0	10.0	2.8
Standard Deviation	523.4	5.2	3.1	-	-	1.5	-	-	1.5	1.3	2.4	-

Table VII-4. Summary of Storage Mode Data

Generator Number	Total Test Hrs	Number* Maint Actions	Number Chargeable System Failures	Number* Maint Act per 1000 Hrs	Number Chargeable System Failures per 1000 Hrs	Chargeable System Failure Time (Man-Hrs)	MTBF (Hrs)	MTBMA	Unscd (Man-Hrs)	Scd (Man-Hrs)	Total (Man-Hrs)	Unscd Maint Time per 1000 Hrs
6	502.4	10	4	19.9	8.0	3.0	125.6	50.2	3.0	8.0	11.0	6.0
7	501.3	7	1	14.0	2.0	1.5	501.3	71.6	1.5	8.0	9.5	3.0
8	464.4	12	5	25.8	10.8	11.0	92.9	38.7	11.0	8.0	19.0	23.7
9	502.7	8	2	15.9	4.0	1.4	251.4	62.8	1.4	8.1	9.5	2.8
10	501.5	9	2	17.9	4.0	1.4	250.8	55.7	1.4	7.6	9.0	2.8
Total	2472.3	46	14	-	-	18.3	-	-	18.3	39.7	58.0	-
Mean	494.5	9.2	2.8	18.6	5.7	3.7	176.6	53.7	3.7	7.9	11.6	7.4
Standard Deviation	16.8	1.9	1.6	-	-	4.2	-	-	4.2	0.2	4.2	-

Table VII-5. Summary of Simulated Tactical Use Data

Generator Number	Total Test Hrs	Number* Maint Actions	Number Chargeable System Failures	Number* Maint Act per 1000 Hrs	Number Chargeable System Failures per 1000 Hrs	Chargeable System Failure Time (Man-Hrs)	MTBF (Hrs)	MTBMA	Unscd (Man-Hrs)	Scd (Man-Hrs)	Total (Man-Hrs)	Unscd Maint Time per 1000 Hrs
11	1024.1	5	1	4.9	1.0	1.0	1024.1	204.8	1.0	2.1	3.1	1.0
12	978.2	13	8	13.3	8.2	13.2	122.3	75.2	13.2	3.0	16.2	13.5
13	732.3	15	10	20.5	13.7	13.5	73.2	48.8	13.5	3.5	17.0	18.4
14	1004.0	11	5	11.0	5.0	4.0	200.8	91.3	4.0	4.0	8.0	4.0
15	1002.8	6	2	6.0	2.0	2.5	501.4	167.1	2.5	3.5	6.0	2.5
Total	4741.4	50	26	-	-	34.2	-	-	34.2	16.1	50.3	-
Mean	948.3	10	5.2	10.5	5.5	6.3	182.4	94.8	6.8	3.2	10.1	7.2
Standard Deviation	121.8	4.4	3.8	-	-	6.0	-	-	6.0	0.7	6.2	-

*Excludes oil changes.

SECTION VIII. CLIMATIC CHAMBERS VERSUS NATURAL ENVIRONMENT

A. INTRODUCTION

Periodically, questions arise concerning the necessity for Department of the Army testing of materials and materiel in adverse natural environments represented by the Arctic, Desert, and Tropics. The need for testing under extreme climatic conditions, as defined in AR 70-38, is rarely questioned; the controversy usually centers around the validity of reproducing these conditions in climatic chambers and laboratories. Chamber advocates point to advantages of lower cost, shortened test times, and ability to impose strict laboratory controls to enhance understanding of results. Environmental advocates point to possible synergistic effects, the large number of natural variables, and problems in selecting those to be chamber-simulated, human factors considerations, restrictions on functional or dynamic tests in chambers, and the high dollar risk resulting from an invalid laboratory test. Chamber and natural environment tests play complementary roles in the development cycle. Chamber tests are important screening tools in early stages of development. The natural environment test provides confirmation of the suitability of items that perform favorably in chamber tests.

This section summarizes results of a USATTC literature survey of studies which compared laboratory and chamber test results with those from natural exposure tests. The section also includes the results of a USATTC study to assess the feasibility of employing a tropical greenhouse to simulate natural environmental effects.

B. LITERATURE SURVEY RESULTS

Dobbins and Downs (1973) compiled available literature on comparison of chamber and field test results. The comparisons concentrated on tropic exposure and storage tests and the associated variables of high heat and humidity; however, some articles reflecting comparisons in other environments were included when the results seemed appropriate. The following conclusions were drawn by USATTC.

> Attempted correlations between chamber tests and natural exposure tests yielded highly conflicting results. Some experiments were successful, but most were unsuccessful or successful only to a limited degree. Tropic exposure effects, in particular, were not accurately predicted by laboratory or chamber tests.
>
> Chamber tests are susceptible to better experimental control, better identification of cause-effect relations, earlier results, smaller sample size, and more reproducible results than natural tests. Tropic field tests result in a wide range of effects because there are numerous subenvironments (e.g., mangrove swamps,

fern forests, rain forests, palm swamps). In addition, results obtained within the same subenvironment are also highly variable, requiring many test item replicates to stabilize the average effect in field tests. The natural tropic environment is typified by the presence of many interacting variables such as high temperature, intense radiation, high humidity, organic and inorganic deposits, vegetation effluents, and biological agents.

The survey results suggested that when the failure mode of an item in outdoor exposure can be identified, it may be possible to successfully simulate it in the laboratory. For example, moisture, temperature, and salt spray effects were successfully simulated. Less sucessful results in some laboratory tests may have been caused by lack of knowledge of the joint (interaction) effects of many variables operating simultaneously.

The techniques employed in the survey to induce accelerated testing were both highly variable and experimenter-dependent. Where correlations were not found, the laboratory tests appeared to be overly severe in some cases and not severe enough in others, or the tests had little apparent relevance to the environment being simulated.

In simulating the tropics, one particularly difficult problem is encountered. Both sunlight and fungi are known causes of deterioration but are incompatible when tested simultaneously. When accelerated actinic damage is attempted in tne laboratory, high light levels are required which inhibit or kill the fungi. Further, intense lighting usually results in a heating effect which desiccates experimental samples and kills potentially destructive organisms. This is a limiting factor in realistic weather-o-meter simulation of tropic conditions.

The studies relating simple (single-variable) chamber tests to complex (multivariate) chamber tests yielded important results that permit speculation about the poor overall correlation between simple laboratory tests and field tests. Simple chamber tests accomplished sequentially did not predict the results of complex chamber tests in which the same variables were applied simultaneously. The results were generally attributed to joint effects operating in the complex tests. The risk/cost consequence of the inexpensive, simple but invalid laboratory test must not be minimized. The dilemma facing those who would substitute low risk chamber tests for natural tests is that more and more variables must be designed into the simulation, and larger and larger chambers must be designed to allow for dynamic function testing. However, as the risk drops, the simulation system becomes extremely expensive.

In terms of most of the significant dimensions of the military materiel acquisition cycle-time, cost, convenience and precision-chamber tests are highly preferable to field tests. In terms of risk, however, present laboratory and chamber test technology is not sufficiently advanced or predictive to replace natural tropic tests. The survey suggests that chamber and field tests of material deterioration be continued in their present confirmatory and complementary relationship within the US Army developmental cycle.

MIL-STD-810C* provides guidelines for temperature and humidity testing in chambers that allegedly simulate the natural environment. The preponderance of published evidence indicates that chambers rarely simulate tropic effects.

C. ASSESSMENT OF A "TROPICAL GREENHOUSE" CHAMBER METHODOLOGY

USATTC, in conjunction with White Sands Missile Range, conducted a 1-year study to assess the utility of a tropical greenhouse for predicting materiel performance in the humid tropics (Dement and Calderon, 1979). The tropical greenhouse represented a new approach to chamber simulation in that it included solar radiation, rainfall, vegetation, soil and associated microbes in addition to high heat and humidity. Test items representing optical, electronic, pneumatic, hydraulic and mechanical materiel were exposed to the tropical greenhouse and MIL-STD-810C fungus chamber environment at White Sands and to open and jungle exposure in the Canal Zone. Some units were maintained in air-conditioned laboratories at the two sites for control. Effects of the different environments on the test items were measured in terms of test item performance and system/component failure rates.

Performance data collected on the pneumatic/hydraulic/mechanical systems were used to compare the various exposure modes. The units in all environmental exposures exhibited degradation in performance relative to those in control exposure. The environmental exposures were compared by fitting curves to the field exposure data and measuring the fit of the simulated exposure data to these curves (figures VIII-1 and VIII-2). The correlation coefficients for all comparisons are presented in table VIII-1. The numbers of failures per 1000 exposure hours measured after 36 weeks of exposure are presented in table VIII-2. In terms of both performance and failures, the greenhouse results are closer to field results than those from the fungus chamber.

Optical system performance data from the greenhouse exposure were not valid after a short period of exposure due to contamination of the lens system by corrosion products. Changes in transmissivity of the lens are presented in table VIII-3. The greenhouse exposure was statistically more severe than the open site which was more severe than the jungle and fungus chamber exposures. All environmental exposures

*MIL-STD-810C, Environmental Test Methods, 10 March 1975.

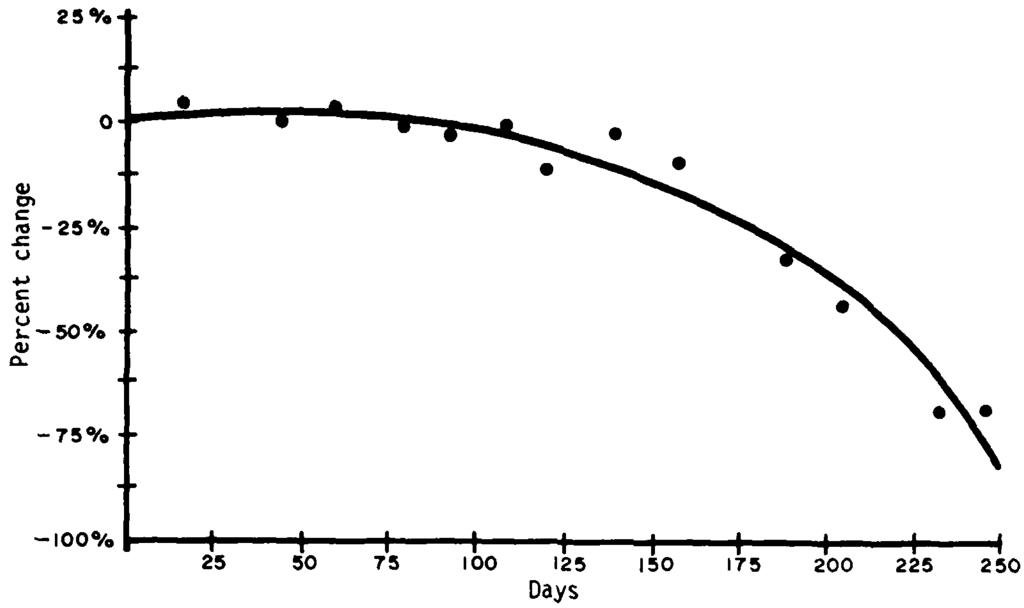


Figure VIII-1. Curve Fit to Jungle Performance Data (Pneumatic/Hydraulic/Mechanical System--40 psi).

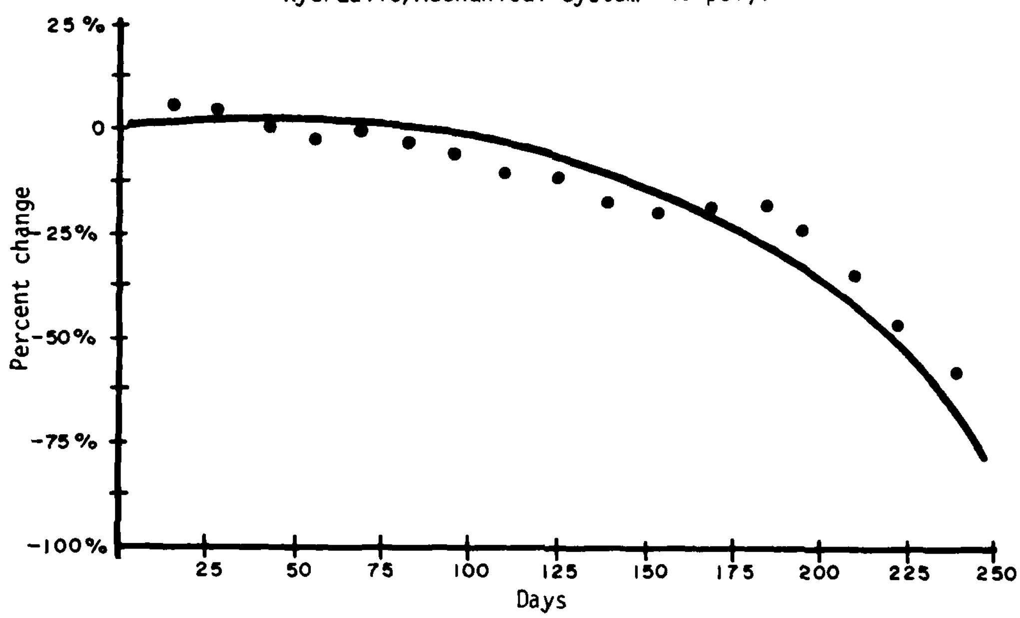


Figure VIII-2. Greenhouse Performance Data Compared to Juncle Curve (Pneumatic/Hydraulic/Mechanical System--40 psi).

Table VIII-1. Correlation Coefficients for Pneumatic/Hydraulic/ Mechanical System Data Fit to Model Curves

Model	Data	25 psi	40 psi
Jungle	Jungle	0.9000	0.9866
	Greenhouse	0.9121	0.9804
	Fungus Chamber	0.7641	0.9467
Open	Open	0.9756	0.9938
	Greenhouse	0.8031	0.9331
	Fungus Chamber	0.6746	0.8501

Table VIII-2. Pneumatic/Hydraulic/Mechanical System Failure Rates

Exposure	No. of Failures	Exposure Time (x1000 hrs)	No. of Exposure Items	Total Exposure Time (x1000 hrs)	Failure Rate (Failures/1000 Exposure hrs)
Jungle Site	3	6	5	30	0.100
Open Site	8	6	20	120	0.067
Tropical Greenhouse	6	6	20	120	0.050
Fungus Chamber	0	6	5	30	0.000

Table VIII-3. Lens Transmissivity: Mean Change for Total Test Period

Site	Mean Change (Ohms)	Standard Deviation
USATTC Control	20	14
USATTC Jungle	132	73
USATTC Open	298	142
WSMR Control	32	29
WSMR Greenhouse	1633	1534
WSMR Fungus Chamber	89	51

were more severe than the control exposures. Analysis of optical system failure data using the Chi-square test indicates that the occurrence of device failure at each environmental site was significantly greater than that at the control sites. Comparison of failure data among environmental exposure sites indicated that the open site was less severe that the other three sites which did not differ significantly.

The digital electronic system performed well in all exposure modes.

The tropical greenhouse environment produced results closer to those obtained in the field than the fungus chamber environment; however, only general correlation between greenhouse and field results were obtained. These results suggest that the greenhouse approach might provide a more valid prediction of tropic performance than the standard chamber methodology.

No significant acceleration of degradation was noted in either the chamber or greenhouse environment. The results suggest that acceleration of degradation processes occurring in the humid tropics may not be feasible.

SECTION IX. VEHICLE MOBILITY

A. INTRODUCTION

Many factors of the environment influence the ability of a vehicle to move cross-country. Most significant are soil type and strength, slope and surface micro-irregularities, vegetation stem size and spacing (and the attendant obscuration), and linear features such as stream and road embankments. Some of the terrain factors vary temporally; soil strength varies primarily with changes in soil moisture content which in turn is influenced by rainfall.

For a number of years research sponsored by DARCOM and other Army organizations has been conducted in an effort to quantify relations among terrain, vehicle, and driver parameters. Because of an inability to simulate natural conditions in the laboratory, emphasis has been placed on the study of vehicle performance and related subjects in the natural environment. Considerable effort has also been expended on development of mathematical models for predicting vehicle speed in the on- and off-road context, standardization of techniques for classifying and quantifying terrain attributes in terms of model inputs and design of model output formats to meet various user applications.

This section includes background information on the results of field exercises and special studies conducted in the Republic of Panama. The results of these operations include recommendations for further study to improve the capability for cross-country operations in tropic environments. Much of the foundation for USATTC research and development was based on findings from tropic operations conducted in the early 1960s. This section also includes a brief overview of a method for measuring and presenting soil trafficability, and soil moisture strength studies.

B. VEHICLE OPERATION IN THE TROPICS

A series of environmental operations was conducted by the US Army Transportation Board to investigate the suitability of military and commerical vehicles to operate in the tropics. The series began in November with Operation Tropical Wet (November to December 1960) which was followed by Swamp Fox I (August to September 1961) and terminated with Swamp Fox II (August to November 1962). The reports of these operations contained information important to planning and conducting tropic operations as well as guidance for research and development on vehicle mobility.

These studies consisted primarily of off-road operations using a variety of vehicles in test areas which ranged from virgin jungle to grasslands. The exercises revealed that:

Vegetation in forested areas and surface soil slipperiness on steep slopes and in narrow, deep gullies cut by streams were the major obstacles to mobility. Except for marshy areas mass soil strength was not an important hindrance to vehicle movement.

Rocks, stumps, logs and brush limited the movement of low clearance vehicles.

Tracked vehicle performance was superior to that of tactical wheeled vehicles, although wide, high-flotation tires with deep cleats improved vehicle performance to a point that was comparable to that of conventional tracked military vehicles.

The only mobility problems presented by grasslands were hidden obstacles and entanglement of vegetation in the running gear.

Winches were essential for negotiating steep slopes and crossing rivers.

Chains increased the mobility of wheeled vehicles.

Maintenance requirements were high during jungle operations.

C. TRAFFICABILITY

Trafficability is defined to be the capacity of soils or other surface media to support ground crawling vehicles. This section provides a brief description of the methods of predicting trafficability based on soil and slope data. Detailed methods can be found in Chapter 9 of TM 5-330, Planning and Design of Roads and Air Bases and Heliports in the Theater of Operation, September 1968.

Measurement of Trafficability

A vehicle traveling cross-country must overcome the resistances to motion caused by soil, slope and surface obstacles such as drainage features and vegetation. The ease with which a vehicle traverses an area is dependent upon the excess traction available to accelerate the vehicle or overcome resistances caused by slopes and obstacles. The extent to which excessive traction can be utilized in maintaining a safe speed will also be controlled by surface roughness, discrete obstacles, and visibility.

Soil Measurement. Soil trafficability measurements consist of several indices obtained with a special soil test set which includes a cone penetrometer, soil sampler and remolding equipment. The cone penetrometer is used to measure the shearing resistance of the soil expressed as cone index (CI). The gain or loss of soil strength to be expected under vehicular traffic is measured with the remolding equipment which provides a remolding index (RI); the RI is the ratio of the

remolded soil strength to its original soil strength as measured in terms of CI. The average CI readings for a given soil layer are multiplied by the RI for the same soil layer to obtain the rating cone index (RCI) which is the soil strength expected from vehicular traffic.

Measurements of the above soil strength indices are made in the critical layer which is the soil layer in which the RCI (fine-grained soil) or CI (coarse-grained soil) is considered the most significant measure of trafficability. Its depth varies with weight and type of vehicle, as well as with the soil profile. Generally, the critical layer for different soil types is defined as follows:

a. Fine-grained soils: Six to 12 inches below the surface when subjected to 50 passes of a vehicle. Surface to 6-inch depth when subjected to one pass of a vehicle.

b. Coarse-grained soils: Surface to 6-inch depth for all vehicular passes.

Fine-grained soil properties that can also influence trafficability when the soil is wet are stickiness and slipperiness. There are no quantitative measures of these properties that have been related to soil trafficability. Under extreme wetness conditions, sticky soils can accumulate in the running gear of a vehicle to the point where travel and steering are difficult. The presence of excess surface water or a layer of soft plastic soil overlying a firm layer of soil can produce a slippery surface for wheeled vehicles and tracked vehicles with rubber insert road track pads. On a slippery surface, the traction elements may experience high slip with little rutting. Wet vegetation on firm fine-grained slopes will limit their negotiability. Such conditions are very common in the wet and humid tropics, and during rain the inability of wheeled vehicles to negotiate slopes less than 10 percent is not uncommon.

Seasonal changes will produce changes in the trafficability of a soil. When significant rains occur, fine-grained soils undergo an increase in moisture content, with resultant increased slipperiness and stickiness and decreased strength. Dry periods have opposite effects. Clean sands improve in trafficability through an increase in cohesion during rainy periods but return to a loose and therefore less trafficable state during dry periods. To account for changes of soil moisture content on soil strength, special prediction techniques are required.

Slope. In order for a vehicle to negotiate a slope it must overcome the combined resistances of surface features and gravity. Soil vehicle tests on level and sloping terrain have shown that if the same soil conditions exist on both level and sloping terrain, the tangent of the maximum slope angle that a vehicle can negotiate is equal to the traction coefficient (drawbar pull, pounds/vehicle weight, [illegible] that the vehicle can develop on the level soil surface.

Vegetation. In addition to the effects that soil and slope may have on vehicles operating off-road, many areas are covered with vegetation which can deter motion in the sense that additional tractive effort is required to override or maneuver around trees. To account for the resistance to movement caused by grass and woody tropic vegetation, USATTC (Davis, et al., 1974) conducted special studies with selected military wheeled vehicles to develop pertinent relations.

Figures IX-1, IX-2 and IX-3 show the relation between stem diameter and force required to fail and override a tree with the vehicles tested. On each plot is shown the force (F) equation derived for the empirical relation shown and the correlation coefficient (r). It must be remembered that overriding and maneuvering around trees produces a high number of vehicle component failures as well as body damage. Figure IX-4 shows a relation between single tree force and average multiple tree force override. As indicated by the linear relation, override of multiple stems of a given size requires about 1.10 times the force of single stem of that size.

Determining Vehicle Performance

In order to predict vehicle performance the vehicle cone index, appropriate soil strength index (rating cone index for fine-grained soil and cone index for coarse-grained soils), slope and other resistances to movement such as vegetation must be known. The vehicle cone index (VCI) is a property of a specific vehicle which indicates the minimum soil strength in terms of the RCI required for one pass (VCI_1) or 50 passes (VCI_{50}) of the vehicle. The VCIs are computed from vehicle characteristics and are available for military vehicles. When the RCI is equal to VCI_1, the soil has sufficient shear strength for the vehicle to overcome its motion resistance. Low VCIs indicate that the vehicle is capable of traversing soft soil areas. If the vehicle is required to tow another vehicle, negotiate a slope or override vegetation additional soil strength is required for mobility. The predictions are valid for cases where mobility is controlled by mass soil strength alone. When a large discontinuity exists between surface conditions and underlying mass soil strength, quantifying vehicle performance is not possible because of the difficulty in measuring the shear strength of thin, weak surface materials underlain by firm soils and the transient nature of surface slipperiness.

The relation between vehicle performance controlled by mass soil strength, slipperiness, and a combination of both is presented as a concept in figure IX-5. As the mass soil strength increases, performance increases (as shown by the solid line) until soil strength has little or no effect on traction performance. If the firm, fine-grained soil surface contains free water or mud, wheel performance will be decreased to approximately that shown by the dashed line.

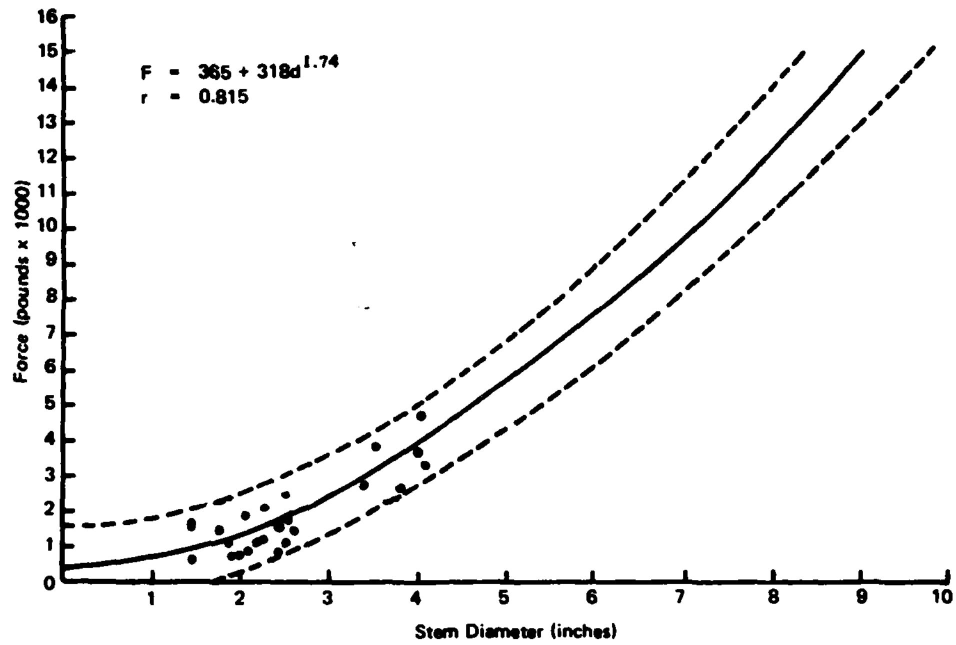


Figure IX-1. Force Required to Fail and Override a Tree with an M151A1, 1/4-Ton Truck.

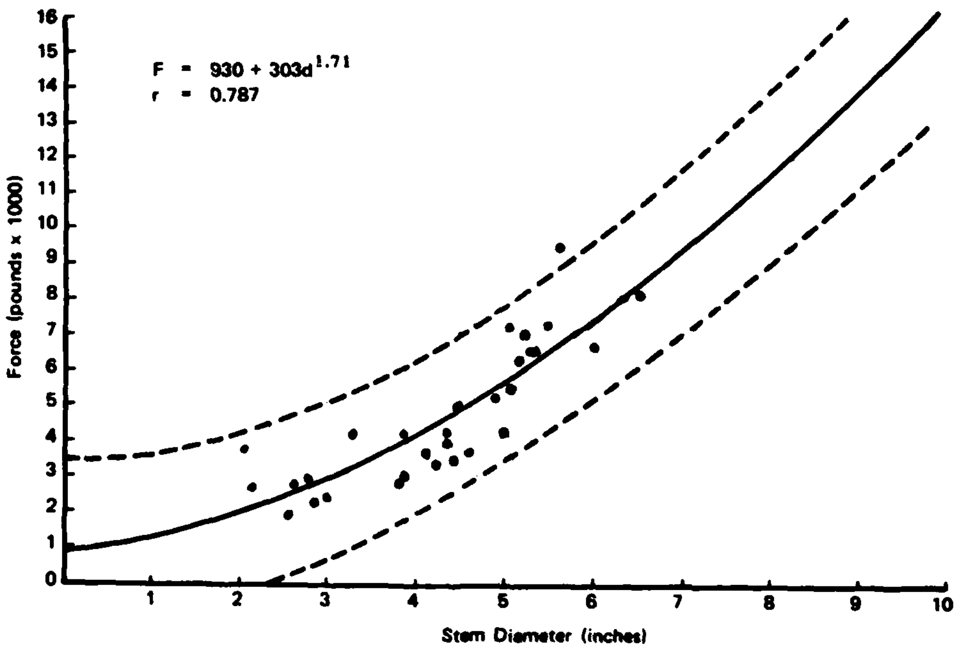


Figure IX-2. Force Required to Fail and Override a Tree with an M715, 5/4-Ton Truck.

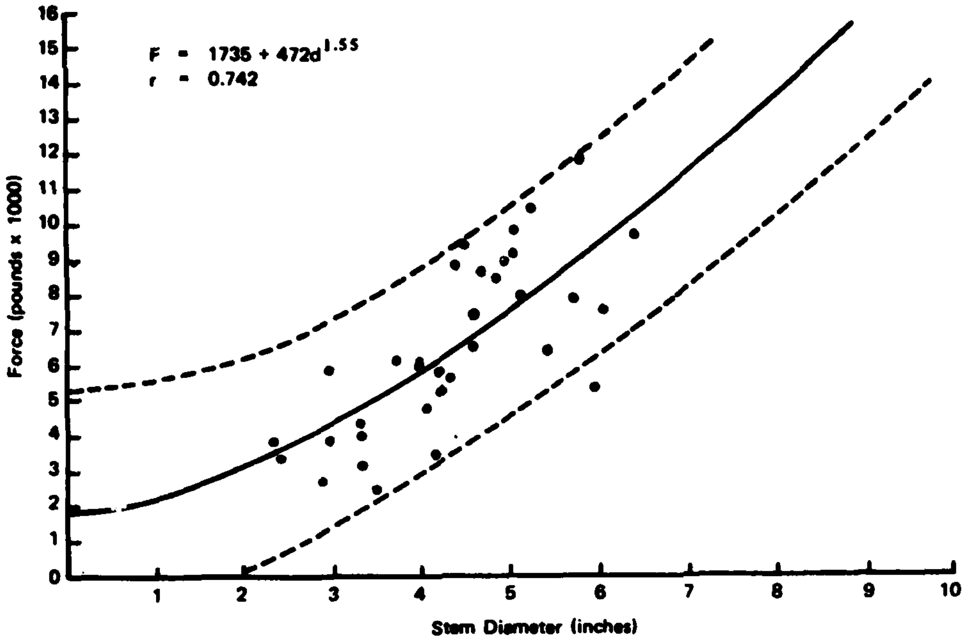


Figure IX-3. Force Required to Fail and Override a Tree with an M36A2, 5/2-Ton Truck.

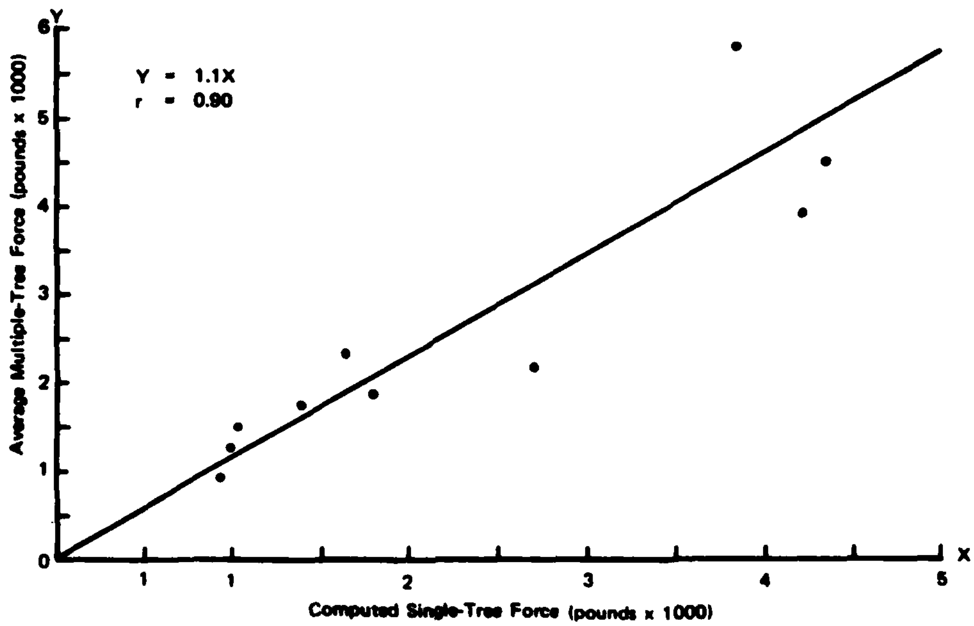


Figure IX-4. Comparison of Single- and Multiple-Tree Force Required to Fail and Override.

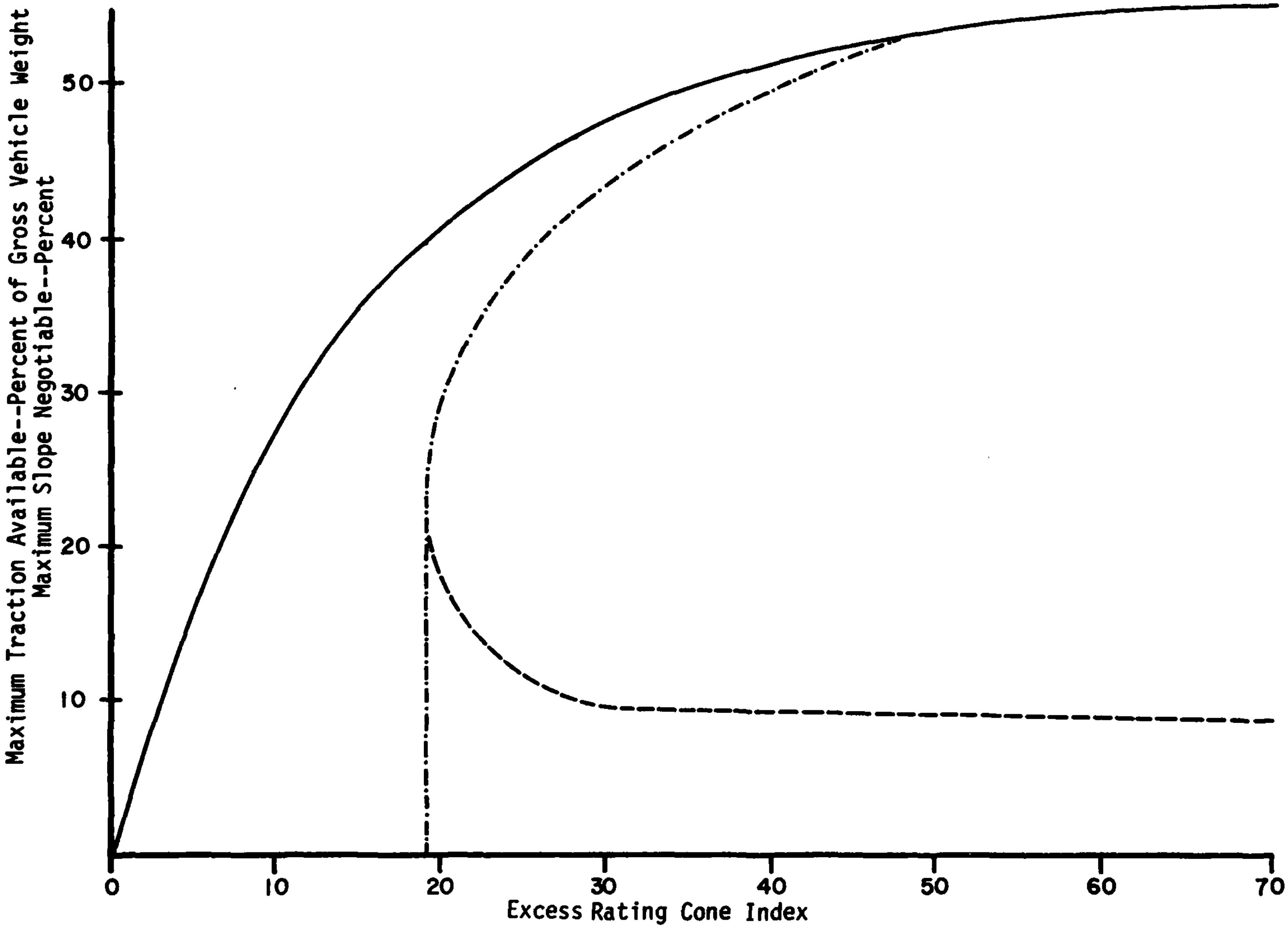


Figure IX-5. Performance of Wheeled Vehicles on Various Fine-Grained Soil Surfaces.

Experience obtained from testing wheeled vehicles on slopes with various surface covers and wetness conditions indicates that such a relationship exists. The region between the solid line and the dashed and circled line represents an area of transition in which performance is controlled both by mass and surface soil strength. In this zone, free water present on the surface is mixed into the soil by vehicle traffic, reducing the mass soil strength. As shown at the higher rating cone index values, the relation for slippery surface performance is transient. When the surface dries, trafficability becomes dependent upon mass soil strength and the vehicle can achieve its maximum traction performance.

D. SOIL MOISTURE--STRENGTH STUDIES

As previously noted, the ability of soils to support ground crawling vehicles is dependent upon bearing and traction capacities of the soil, both of which are functions of shear strength of the soil. Studies have shown that the strength of a soil varies primarily with soil moisture.

As part of USATTC's Environmental Data Base for Regional Studies in the Humid Tropics (1967), a program designed to increase knowledge of militarily significant environmental factors of the humid tropics, a soil study was conducted emphasizing factors related to soil trafficability and ground water. Detailed data were collected at two sites on the Pacific slope (Albrook and Chiva Chiva) for a period of one year (February 1965--March 1966). The Albrook site was on a flat, forested terrace and the Chiva Chiva site was in flat, grassy bottomland.

Monthly soil moisture profiles for the two sites are presented in figures IX-6 and IX-7. The numbers shown on each plot represent the day of the month on which the site was sampled. Both sites exhibit similar wet and dry season profiles except that the moisture content is higher at the Albrook site. In the dry season the change in moisture content with depth is small. In the wet season, the 0- to 6-inch and 12- to 18-inch layer are wetter than the intermediate 6- to 12-inch layer. The top layer moisture content is influenced by frequent rains and the lower layer moisture content is influenced by the water table.

Monthly soil strength profiles in terms of cone index were also prepared. The cone index profiles reflected to a certain degree the moisture content. Cone index increases with depth and the rate of change is dependent upon moisture content profile. The higher moisture content profile at the Albrook site also yielded a lower cone index profile.

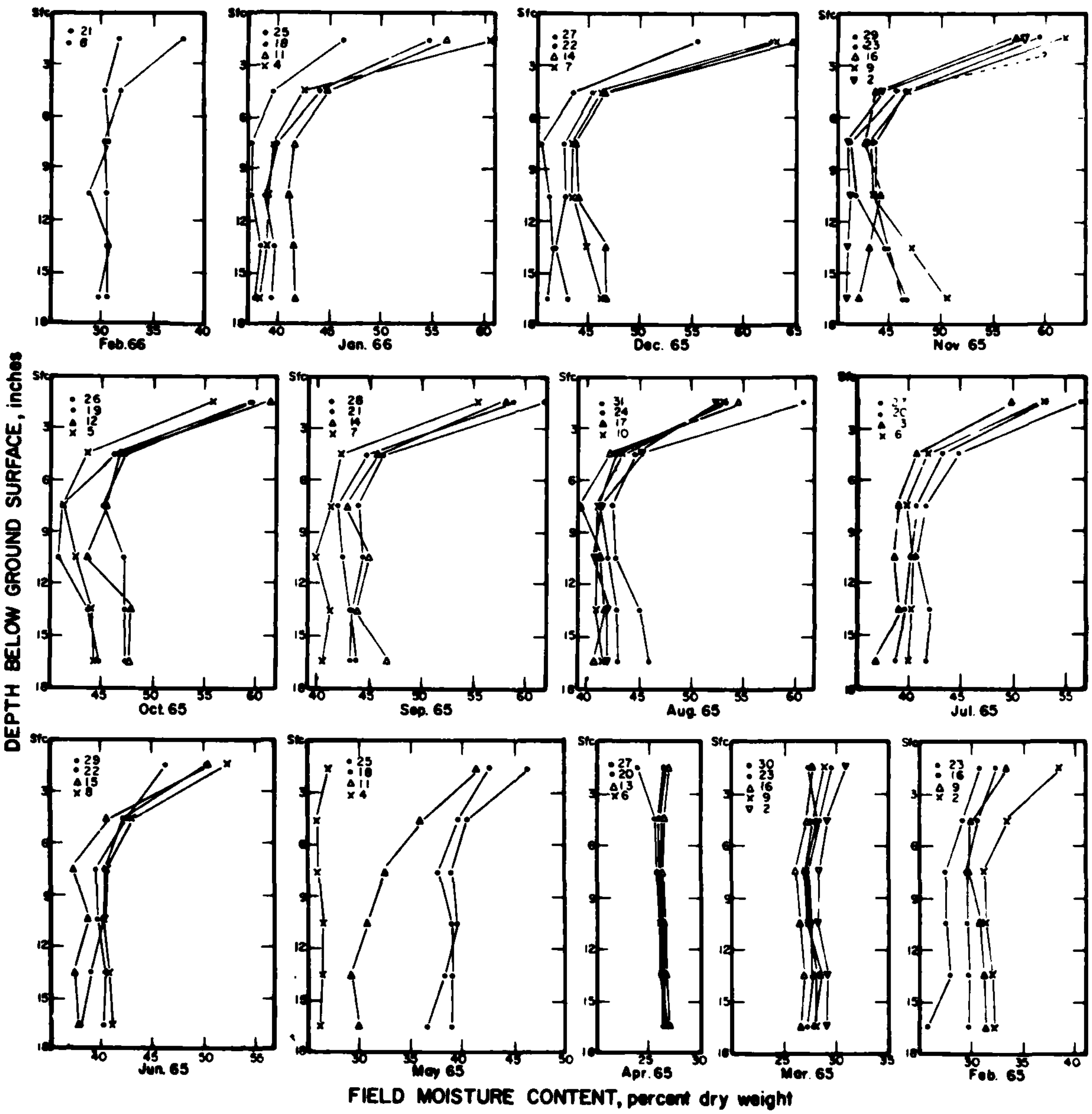


Figure IX-6. Monthly Variation of Natural Field Moisture Content with Depth--Albrook Forest Site.

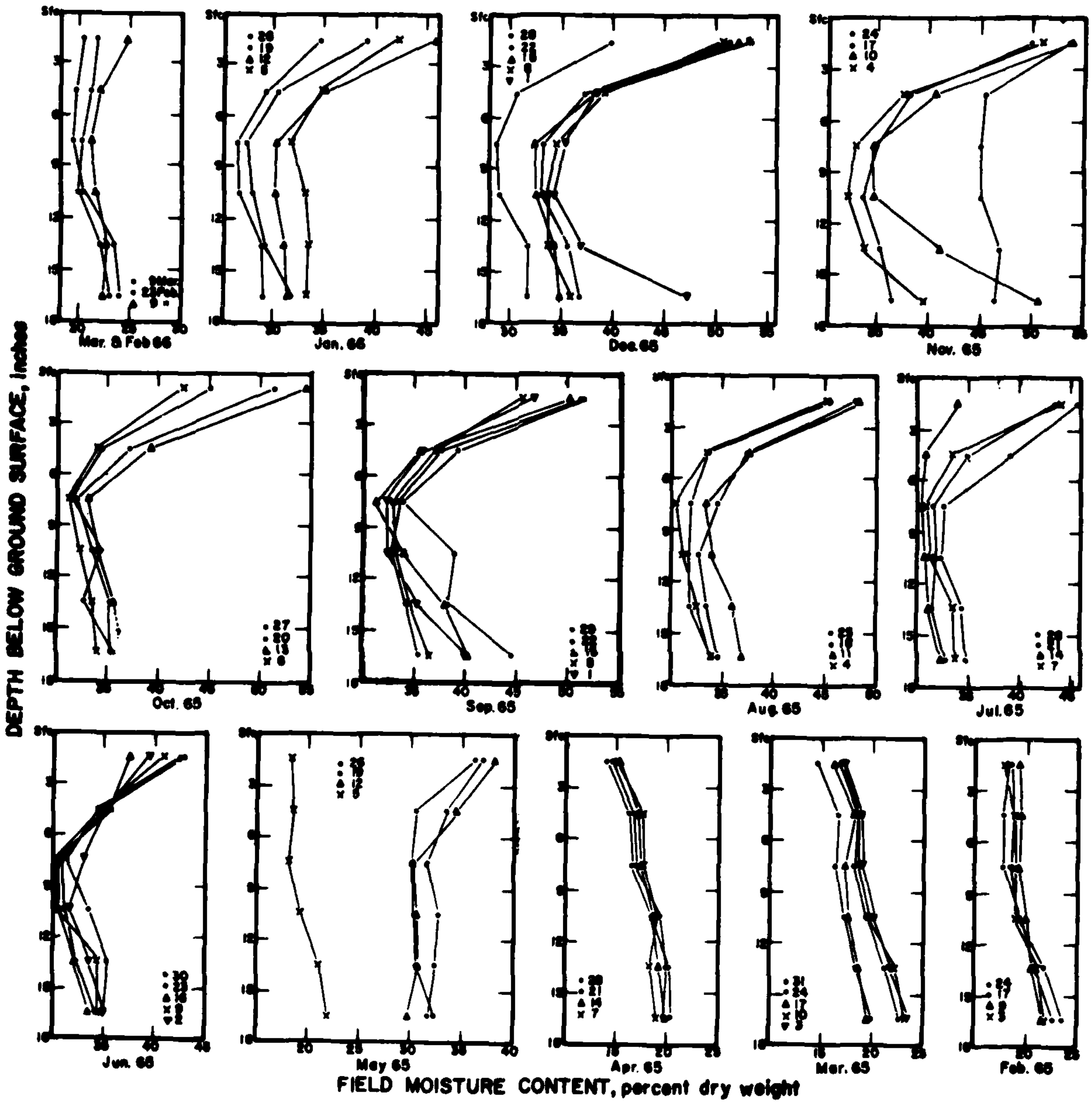


Figure IX-7. Monthly Variation of Natural Field Moisture Content with Depth--Chiva Chiva Site.

Moisture content-cone index relations by 6-inch layer for the basic sites are shown in figure IX-8. As previously mentioned the Albrook site cone index is lower than at the Chiva Chiva site. At high moisture content, the moisture content-CI relation is similar at the basic sites, but as moisture content decreases differences in CI between layers at the same moisture content increase.

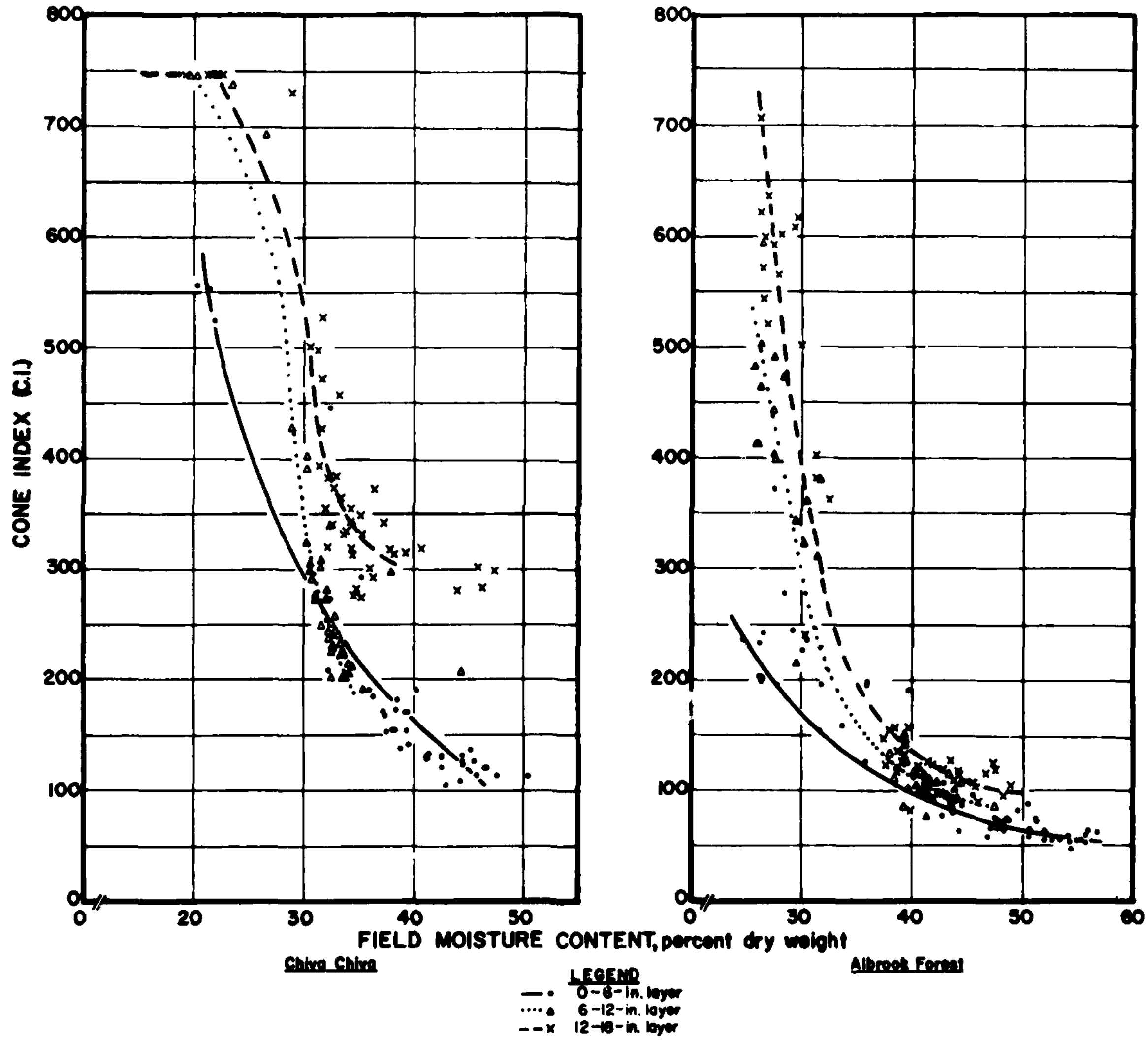


Figure IX-8. Cone Index--Soil Moisture Relation by 6-Inch Layers--Chiva Chiva and Albrook Forest Sites.

SECTION X. COMMUNICATION AND VISIBILITY IN THE JUNGLE

A. SOUND IN THE JUNGLE

Sound Transmission

Sound behaves differently in the jungle than in open areas, primarily because of the mass of vegetation. Human auditory responses are also influenced by vegetation. Dobbins and Kindick (1966) of USATTC conducted a series of physical transmissions of pure tones, ranging from 63 to 800 hertz (Hz) generated horizontally along jungle paths and measured at progressively increasing distances from the sound source.

Results indicated that the jungle acts as a low-pass filter to audible sound. Lower frequencies pass relatively unaffected, while higher frequencies are effectively attenuated. For example, a 63-Hz tone was reduced in intensity by 41 decibels (db) through 400 feet of jungle, while an 8000-Hz tone was reduced in intensity by 79 db through 400 feet of jungle (figure X-1). By contrast, the transmission loss for a 63-Hz tone over 400 feet of open terrain was 39 db, while the transmission loss for an 8000-Hz tone was 52 db over 400 feet of open terrain.

These results were obtained when pure tones were transmitted under a jungle canopy at a height of 5 feet above the ground. In a USATTC study (unpublished, 1977) of pure tones and "pink noise" (sound with constant energy per octave of bandwidth), it was found that sound transmitted horizontally very near the ground was attenuated more than sound transmitted at greater heights. Transmission frequencies ranged from 20Hz to 20KHz and the results in figure X-2 for "pink noise" measured at 50, 100, and 200 feet from the sound source show the attenuation clearly. Pure tones at 63, 250, 1000, and 4000 Hz showed similar effects.

A later report by Aylor (1972) of the Connecticut Agricultural Stations showed that the short-distance reversals between 250 and 1000 Hz in figure X-1 are related to ground attenuation which causes acoustic cancellation. The cancellation depends on source-receiver separation distance. Thus, while foliage most effectively attenuates higher frequencies, soft soil most effectively attenuates lower frequencies.

Total horizontal signal loss through the jungle varies exponentially. Therefore, linear relationships such as "decibels per foot" cannot be relied on to extrapolate transmission losses.

Background Jungle Sounds

Ambient jungle sounds were studied. The total (all-pass) sound pressure for the 125- to 8000-Hz frequency range averages 60 db.

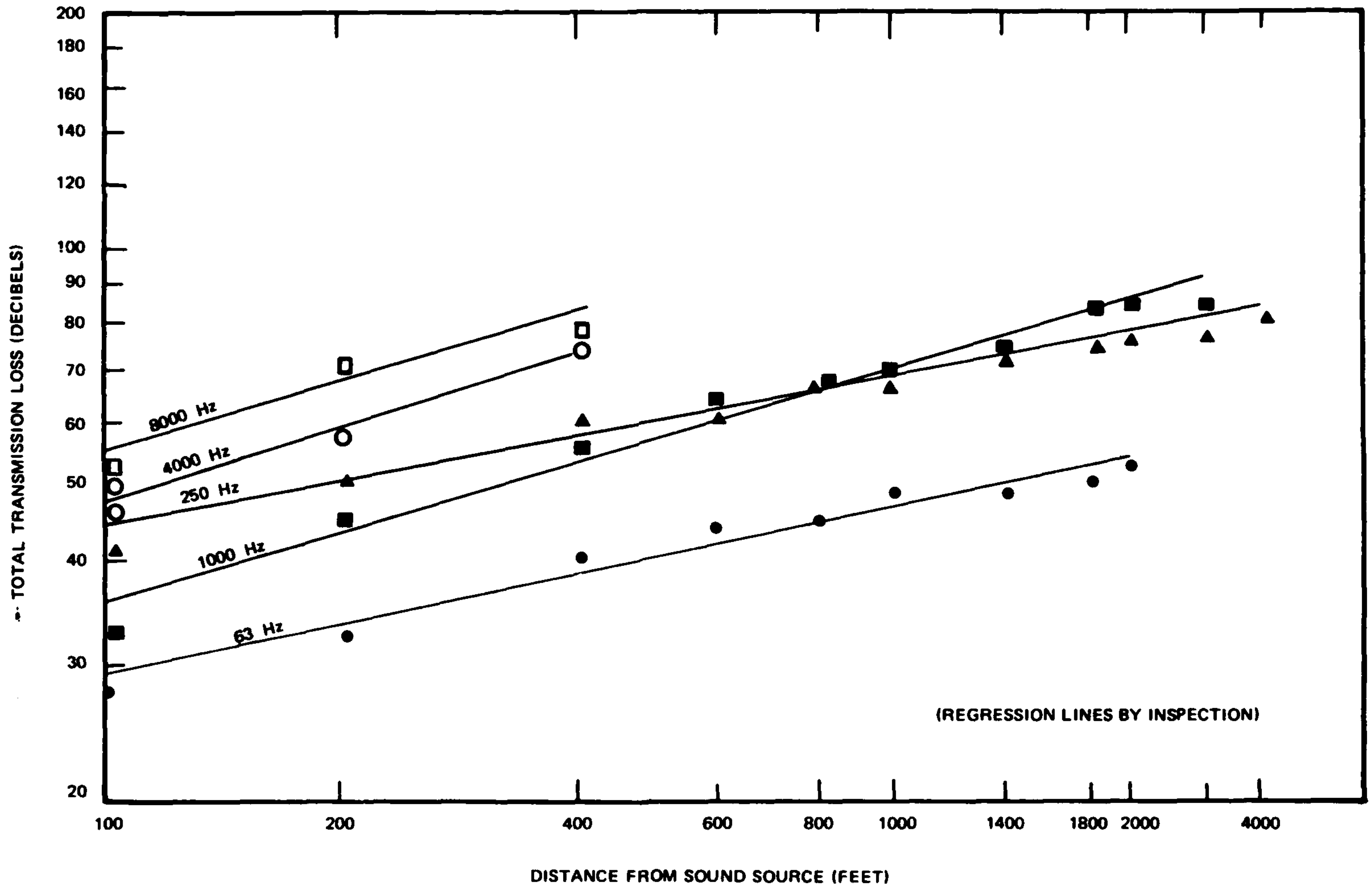


Figure X-1. Total Signal Loss through Jungle as a Function of Sound Frequency and Distance from Sound Source. Signal Loss Was Determined by Emplacing Sound Measurement Devices at Varying Distances from Transmitter at a Height of 5 Feet above the Ground.

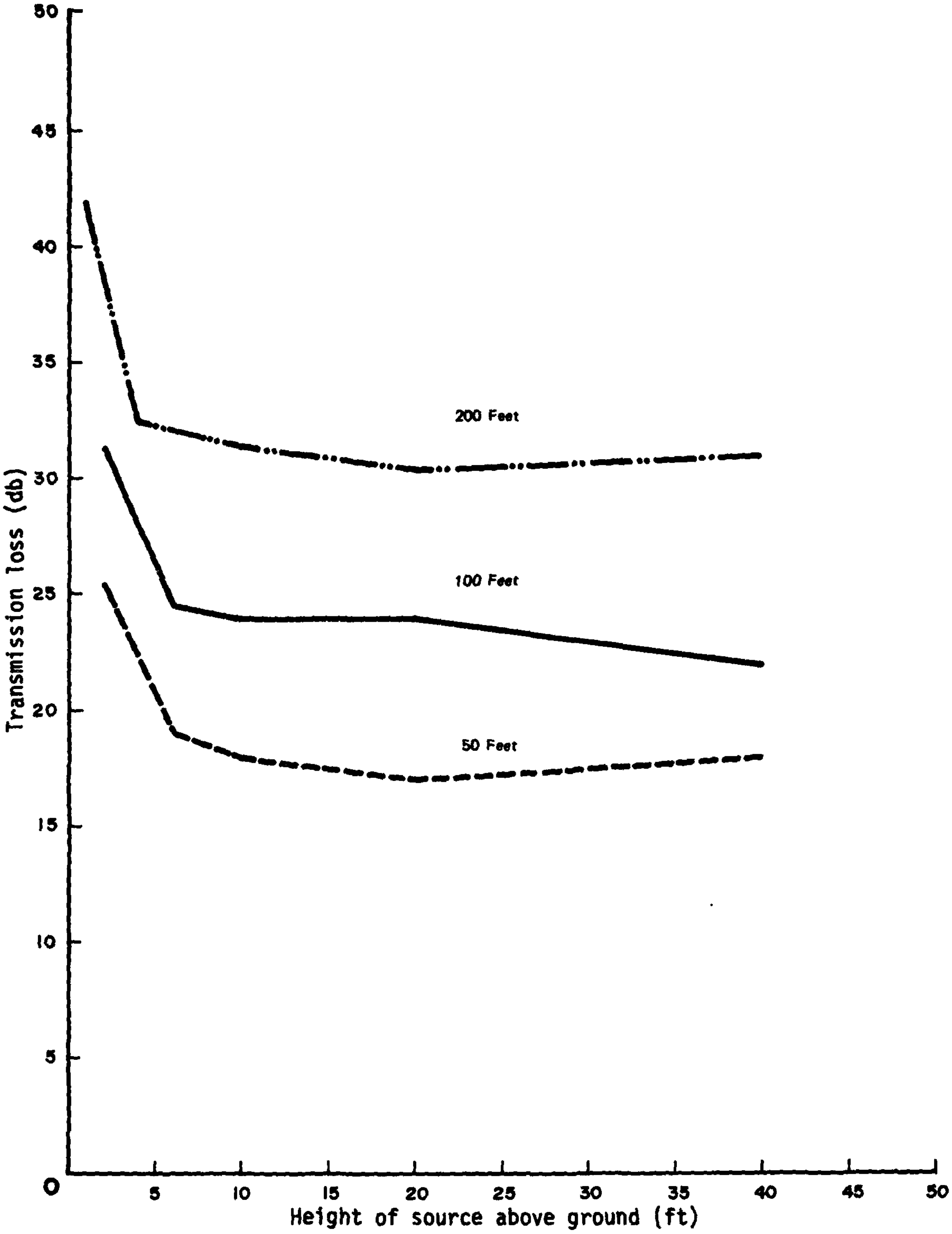


Figure X-2. Total Signal Loss of Pink Noise Transmitted from Different Heights--50, 100 and 200 Feet from the Receiver.

Moderately high noise levels were found from 63 to 125 Hz (e.g., wind rustle, dripping water); low noise levels were found from 250 to 1000 Hz. Noise levels increased rapidly from 1000 to 8000 Hz predominantly due to insect noises. At night, the insect noise increased with a drop in the lower frequencies.

Jungle Listeners

In the USATTC study, soldiers (jungle listeners) were stationed along the same transmission paths and exposed to the same signals as described above. Frequency and intensities were recorded when the sounds first became audible to the listeners. The following conclusions were made:

The point of maximum auditory detectability shifted to the lower frequencies as the listener moved away from the sound source. This was caused by the masking effect of jungle noises and the difference in transmission loss for different frequencies. At distances of 25 to 200 feet through the jungle the 1000-Hz tone was the most detectable, and at 400 feet the most detectable frequency shifted to 63 Hz (figure X-3).

Signals from 63 to 100 Hz were most audible at night because insect noises in the higher frequencies did not mask the signals. Conversely, signals above 1000 Hz were more audible during the day because of the relatively low insect noise.

Human auditory thresholds in the jungle can be predicted when the prevailing ambient noise levels and signal transmission losses are known.

Frequently, listeners can hear signals that are not measurable. This occurs because the human ear and brain have a more efficient filter system to screen out unwanted signals through "selective perception."

The most audible frequency for signaling in the jungle is 1000 Hz, provided that sufficient source acoustic power is available. When power is limited and signals must be heard over a long distance, a 63-Hz signal should be used. If signals must be heard over short distances (200 to 400 feet) but not beyond, the 4000- to 8000-Hz signal range should be used.

With complex noises, such as combustion engines and human voices, the lower frequency components determine the level of audibility. The jungle systematically screens out the high frequency components as the distance is increased from the source.

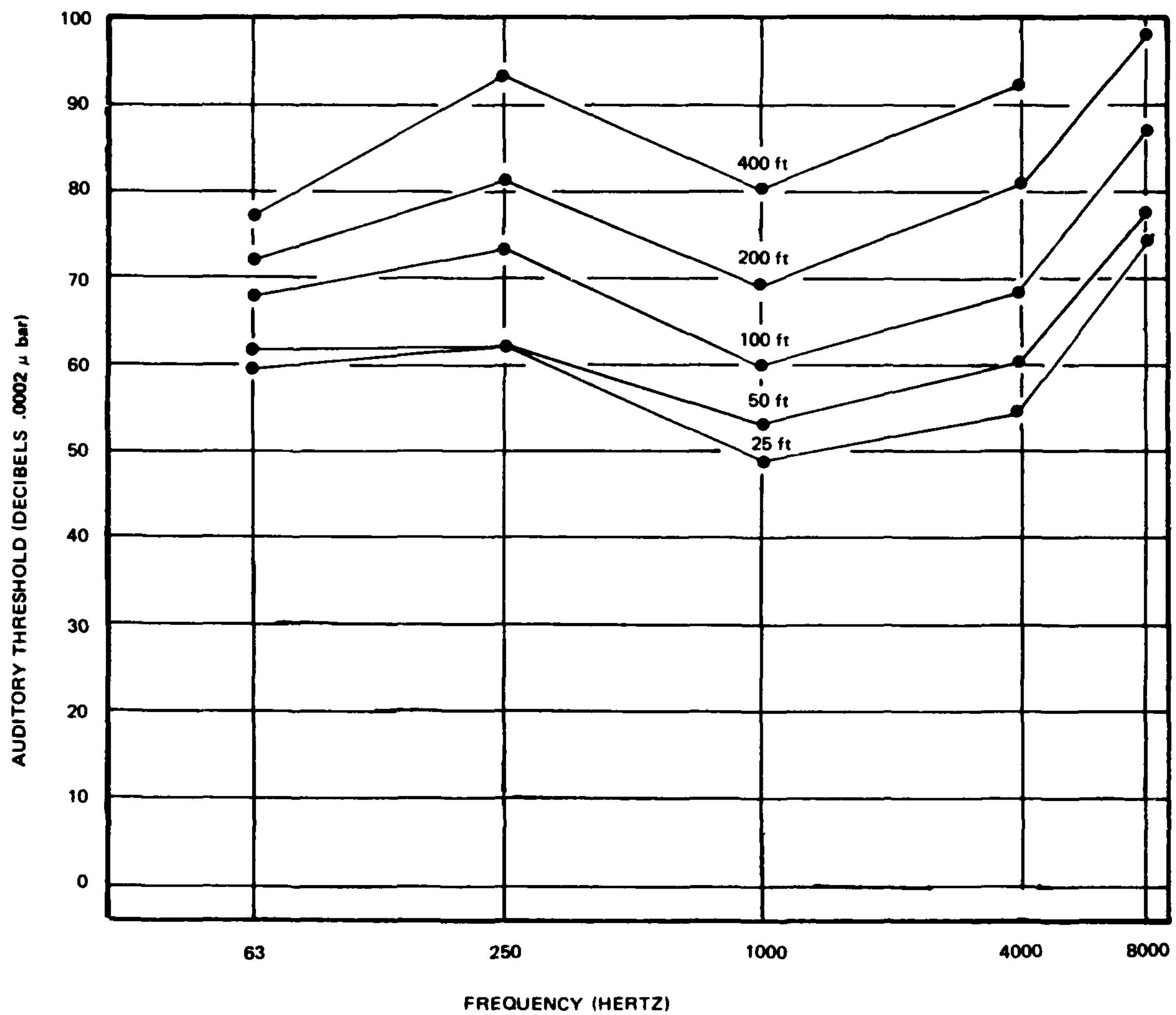


Figure X-3. Mean Auditory Thresholds for 50 Listeners in the Jungle at Various Distances from Sound Source.

Sound Localization

A second study by Dobbins and Kindick (1967) probed the ability of jungle listeners to judge the direction of sound when the target location is unknown. Three types of sounds were transmitted through thick jungle to personnel: pure tones--65 to 6000 Hz; continuous operational noises--walking patrol, moving personnel carrier, human voices, folding and ribbon saws, and a paddled boat; operational impact noises--machete, M14 rifle, and an 81mm mortar. Transmission was intended to reach the listener's head at eight different angles: Front of head, 0°; back of head, 180°; right ear, 90°; left ear, 270° and at 450°, 135°, 225°, and 315°. A listener judged the direction of sound by pointed arrows attached to an azimuth table, and his performance was measured by angular error (in degrees) between the judged direction and true direction. Thus, the angular error could range from 0° (no error) to 180° (maximum error). "Reversal" errors are defined as those between 91° and 180°. The following results were obtained:

> Localization of sound direction was poor in the jungle. Average errors were 39° for pure tones, 29° for continuous operational noises, and 23° for operational impact (figure X-4) noises.
>
> For pure tones, errors were greater in the higher frequencies. The errors became more pronounced when the distance between the source and listener was increased.
>
> Of all responses, 10 percent were reversals. Reversals were highest for pure tones--double that of continuous noises and triple that of impact noises. Reversals increased significantly as the distance was increased between the listener and source. Nonreversal localized errors did not increase significantly with the distance (table X-1).
>
> The angle between the sound source and the listener's head position had a significant effect on the localization error. Sounds were best localized (about a 19°-error) when they came along the right-left axis (directly into the ears). Larger errors (about a 31°-error) were made when the sound came toward the listener's face. The largest errors occurred (about a 46°-error) when the sound came from behind the listener's head. The pattern was consistent for all sounds. It should be noted that with a recurring sound a listener should rotate his head until he thinks the sound comes directly from his left or right. By doing this, he will increase his accuracy by 65 percent for frontal and 145 percent for rear localizations. This head rotation technique must be taught to listeners, because the natural reaction is to turn the eyes toward the sound.

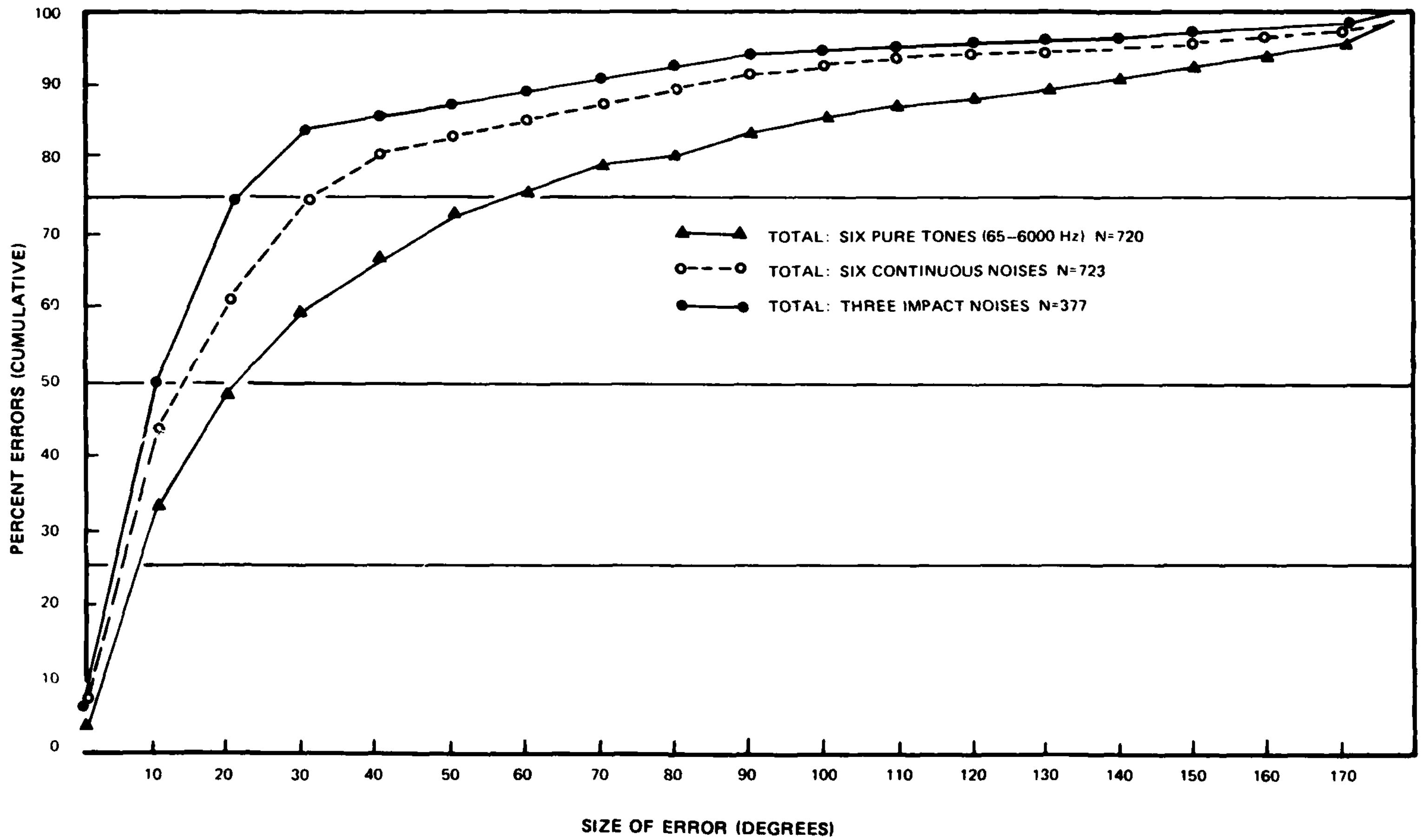


Figure X-4. Cumulative Frequency Distribution Curves of Sound Localization Errors Made by 32 EM Who Subjectively Localized Jungle Sounds (Summed for 200-500 Feet; Eight Direction Angles).

Table X-1. Mean Localization Errors in Degrees for Each Distance for All Direction Angles Combined (0° to 315°)

	Mean (All distances 200,300,400,500 feet) Includes Reversal Errors (91°-180°)	Mean (All distances- 200,300,400.500 feet) Reversal Errors Excluded (91°-180°)
Pure Tones (Hz)		
	17.7	16.6
65	28.9	18.8
200	34.2	22.0
500	50.6	28.4
3,000	62.7	31.3
6,000	Not Available	35.5
Continuous Noises		
APC	23.3	18.8
Folding Saw	23.3	18.6
Boat	23.1	18.1
Patrol	39.1	19.9
Ribbon Saw	33.9	21.8
Voices	34.0	20.4
Impact Noises		
Machete	23.3	13.8
M-14 Rifle	23.1	17.6
81mm Mortar	23.0	14.7

There were other effects in sound localizing. For example, when the sound came at an oblique angle to the listener's head, whether front or back, there was a tendency to judge the sound as coming directly into the ear at a right angle. When the sound actually came to the right-left axis of the head, listeners judged it to be coming from in front of the ear more frequently than from behind the ear.

A supplemental test was conducted at USATTC by Randall and Holland (1972) for the Human Engineering Laboratory to determine whether different types of headgear affect a listener's ability to judge target localization. An experimental helmet (Hayes-Stuart) was used as part of the study (figure X-5). Listeners also wore standard helmets and soft caps, as well as no headgear. Pure tones (125 and 2000 Hz), a continuous noise (voices) and an impact noise (machete chopping underbrush) were transmitted to 32

listeners. The overall experimental design was similar to the first localization study described in preceding paragraphs.

Headgear did not affect capability to judge sound direction in the jungle. Localization errors were approximately the same for all three headgear conditions and for the bareheaded condition.

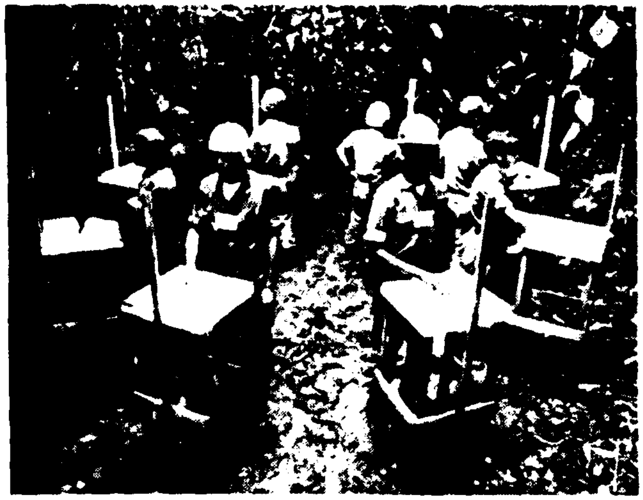


Figure X-5. Use of Azimuth Tables in Jungle for Sound Localization Error Test: Hayes-Stuart Experimental Helmet Versus Standard Hardware.

Acoustic Sensors

Studies were made by Dubuisson and Dobbins (1972) of the capability of acoustic sensors to detect human voices. The sensors were placed at varying elevations in the jungle. As previously discussed, naturally occurring jungle ambient noise levels are unevenly distributed over the frequency spectrum, i.e., moderately high at lower frequencies and very high at higher frequencies. Fortunately, the jungle is relatively quiet in the frequency range of the human voice. Therefore, if an acoustic filter screened out the lower and higher frequencies it might increase the detection of human voices. The study was designed to test this assumption.

Human voices were recorded and then transmitted at slant ranges (600, 900, and 1200 feet) to a tower with microphones placed 5, 20, 60 (mid-canopy) and 100 feet (above canopy). Two reception systems were used to record transmitted voices, one filtered and the other unfiltered. The recordings were played back through headsets to a group of inexperienced listeners (combat MOS). The major results were as follows:

Filtering resulted in a significant increase in detections. Detection percentages were 68 percent for filtered sounds and 50 percent for unfiltered sounds. Filtering superiority was consistent for all elevations, distances, night and day, and experience level of listeners.

At greater distances, filtering became increasingly significant. For example, at 1200 feet 51 percent of the filtered sounds were

detected while only 28 percent of the unfiltered sounds were detected. This result implies earlier detection in an operational setting.

A major disadvantage of the filter is that jungle ambient noises without voices mixed in sounded similar to voices, and a greater number of false detections (i.e., jungle sounds thought to be voices) were made. In an operational setting this could be overcome by allowing the listener to alternate between filtered and unfiltered modes.

Filtering was more effective at night than during daylight hours. This difference probably is explained by the higher level of night ambient noises, even within the bandpass segment of the filtered signals.

Recordings made of sounds above the canopy (100 feet) were more easily detected than those at lower elevations. Detections were lowest for recordings made at the 5-foot elevation.

Experienced listeners were approximately 5 percent more accurate in detection capability than inexperienced listeners.

Personnel Detection

The US Army Limited War Laboratory sponsored a 1964 study by Tatge (1965) for the General Electric Company to determine whether presence of human intruders in the jungle influenced natural animal sounds. If so, the animal sounds could conceivably be used as a personnel detection technique. The experiment was conducted on Barro Colorado Island in the Canal Zone. Controlled tests determined if the animals responded to human activity, and if ambushers could be detected in hiding. All data were tape-recorded at a base facility several thousand feet from the microphones. The recording system including microphones was flat, from 10 hertz to 100 kilohertz. Patterns produced were uniquely identified with particular species of animals giving the history of the sounds produced by each species. The spectrum analyses showed no general change in signal amplitude at any frequency because of intrusion, but several birds that normally live in the lower stratum of the forest changed their rate of call-production (generally a decrease) under conditions of human activity. The rate stayed low for almost an hour after people were active; the effect was virtually the same whether the intruders went into hiding or actually vacated the area. More prolonged tests would be required to establish with certainty whether ambushers could be detected after they had been in hiding for more than an hour. Limited data indicated that ambushers would continue to cause the indicators's rate of call-production to be depressed below that which would be expected under undisturbed conditions. Limited physical transmission loss studies at 10 to 70 kilohertz showed irregularties among many frequencies in signal attenuation

through jungle and trails. It was pointed out that lack of significant temperatures and wind gradients beneath the canopy mean that the velocity of the sound is very nearly the same everywhere, to the extent that refractive effects are not important.

B. RADIO FREQUENCY PROPAGATION IN THE JUNGLE.

Propagation of radio frequency energy in a tropic environment presents a special problem because dense vegetation results in high signal loss. Many DOD agencies have conducted extensive research on electromagnetic wave propagation in tropic environments. These investigations have attempted to develop mathematical models that permit predictions regarding the influence of tropic environments on propagation losses, and have provided detailed information on such environmental parameters as vegetation density and topography.

USATTC conducted a study to establish standard radio frequency propagation courses for future use in evaluating newly developed radio communications system (Kitchen, 1975). In addition, mathematical models developed by other DOD organizations were evaluated to determine their usefulness in predicting pathloss in radio tests.

Two test areas were selected for use in establishing standard radio frequency propagation courses. One area, Coco Solo, is located on the Atlantic side of the Isthmus; the other, Gamboa, is located at Mid-Isthmus.

The field strength 50 feet from the transmitter was measured at the beginning and end of each day and used as the radiated power term in computation in pathlosses. Two pathloss values--one referenced to the field strength at 50 feet and one referenced to a radiated power of 1 watt--were computed along each radial for each of the four frequencies used in this study.

Conclusions were that:

Available mathematical models were too general, were difficult to use in predicting precise pathloss, and would not be applicable to future tests.

Pathlosses measured at the Gamboa and Coco Solo receiver/transmitter sites are repeatable. This indicates that the methodology employed is adequate for use in future radio tests.

Pathloss increases with increasing distance, forest density, soil salinity, and transmitter frequency.

Rough terrain and nonuniform vegetation contribute to variable pathloss measurements between sites that are geographically very close together.

HF and VHF Propagation Efficiencies

During the Swamp Fox II (1964) operation, evaluations were made on the effects of dense jungle growth, hilly terrain, noise and local interference on HF and VHF radio propagation in the jungle areas around Chepo, Republic of Panama. Vertical and horizontal antenna efficiencies and techniques applicable to installations in rain forests were also investigated. The purpose of the test was to improve jungle communications by formulating methods applicable to utilization of antennas and antenna installation equipment that could be useful to small jungle patrols.

During dry season, several tests were conducted. The terrain between receiving sets was varied--open grassland, jungle with and without canopy, along roads, over hills. Different antenna lengths and heights above ground were investigated for clearness of reception. It was found that dense undergrowth reduced signal strength much more than in temperate zone forests, but if antennas were elevated 25 feet or more above ground, receptions were quite satisfactory. When one reception point is low with respect to surrounding terrain, it was suggested that raising the antenna 50 or 60 feet or retransmitting be employed. Recommendations were made that use of VHF be improved because there was no interference as with HF.

RF Propagation by Satellite

From 1967 to 1970, the USAF Cambridge Laboratories (Mullen, 1971) conducted signal attenuation studies at USATTC. The studies had two objectives: determination of ionospheric effects at very high frequency, and determination of foliage effects on VHF satellite signals. Two sites were established--one in a tropical moist forest and one in the open. One satellite was synchronous and two were in polar orbit. Results showed that attenuation of a 40-MHz signal caused by the jungle canopy at low angles (less than 30°) was 3 to 6 decibels. There was no measurable difference between forest and open sites at elevation angles greater than 40° at 136 MHz.

C. SEISMIC ENERGY IN THE JUNGLE

Transducers that sense low-amplitude seismic energy generated by energy sources of military interest are programmed for use in modern battlefield surveillance systems being developed by the United States Army. Seismic Intrusion Detectors (SIDs) have been under development for some time and several models have been deployed in combat. In some cases they worked adequately and in others erratically or not at all. Moreover, the agencies responsible for testing the devices have reported that the systems often perform inconsistently. Whether failure to operate as expected was the result of SID malfunction or lack of seismic energy to activate the SID generally could not be determined with the field procedures used.

The US Army Waterways Experiment Station conducted field methodology investigations in the Canal Zone to establish seismic response characteristics, their distribution, and the environmental factors that influence them. The field data were collected in two phases--3 through 30 March 1971 (Link, et al., 1972) (dry season) and 4 November through 5 December 1971 (wet season) (Marcuson, Leach, 1972). The results of those investigations are summarized in the following paragraphs:

The empirical models tested were not adequate for extrapolating test results or predicting SID performance.

The large site-to-site and season-to-season variations in seismic responses indicate the requirement for site calibration at the time of testing rather than use of existing seismic response maps.

D. VISIBILITY IN THE JUNGLE

Detection of targets in a jungle is a complex activity, dependent on many perceptual abilities.

Unaided Vision

The Tropic Test Center conducted a series of studies to evaluate the capability of personnel to detect targets in the jungle without the use of optical aids. Target radii (five or six) were established in jungle areas separated at 30°-intervals across a search span of 180°. On each radius, six to ten distances were marked. The observers, enlisted in a combat MOS, were stationed at the midpoint of the semicircle. Targets appeared randomly--from one radius to another, and from one distance to another. Both correct and incorrect target detections were recorded. Three primary measurements were made:

Limits of visibility--distance at which percent detection reached zero.

Fifty-percent thresholds--distance at which 50 percent of the targets were detected.

Gradients of visibility--shape of the detection curve from the nearest to the farthest distance.

The soldiers used as observers did not vary greatly in their ability to detect targets. Approximately two-thirds of the observers had detection scores within 10 to 15 feet (3 to 5m) of one another. The method developed has been proven statistically reliable and capable of rendering reproducible results. The method is a field modification of the classic laboratory technique known as "constant stimuli." The 50-percent threshold is a convenient single measure of visibility which can be expressed for a single observer, averaged for sites, type of

forest, or regions. It is used in materiel tests for which the method is appropriate (TOP 1-1-054*).

When searching for men standing motionless in jungle foliage, (Dobbins, et al., 1967) observers most frequently spotted the vertical lines of the trunk and legs. The next most frequently spotted were the head, face, and shoulders. The third most frequently spotted was the dullness of the standard fatigue uniform. The relative symmetry of the body contrasts with the chaotic appearance of the jungle vegetation. This suggests that jungle camouflage should emphasize better obscuration of head-shoulder regions, reduction in size of individual pattern elements and increase brightness of some pattern elements. However, when a silhouette target was covered with US Army camouflage cloth (USAERDL four-color 1948 pattern), the 50% detection threshold distance was 55.9 feet, (17.0m) as compared to 72.3 feet (22.1m) for a standing human target wearing the standard fatigue (OG 107) uniform, and 68.6 feet (20.0m) for the silhouette target painted flat olive drab (Dobbins, Kindick, 1966). Thus the use of the camouflage cloth significantly reduced the visibility or detectability of the target. On the average, observers required from 25 to 45 seconds to detect a standing human target.

Dobbins, et al. (1965--Jungle Vision IV and V), found that colored lenses, designed to enhance background contrast and apparent brightness, did not improve target detections in the semievergreen jungle found on the Pacific slope of the Canal Zone. In the darker moist evergreen forest, found on the Atlantic slope, yellow lenses significantly degraded target detection and reduced depth perception.

When comparing visibility in semideciduous forests with moist evergreen forests, it was found that horizontal visibility is generally higher in the evergreen forest (Dobbins and Gast, 1964; Dobbins, et al., 1965). In the moist evergreen forest (both wet and dry seasons), the 50-percent detection threshold generally ranges from 70 to 75 feet (21-23m); and visibility limits range from 100 to 110 feet (31-34m) (figure X-6). The 100-percent target detectability usually ends between 20 and 30 feet (6-10m).

The moist evergreen forest exhibits low light levels throughout the year under the canopy. Horizontal luminance levels range from 5 to 15 footcandles during the wet season and 20 to 35 footcandles during the dry season. The semievergreen forest is much brighter than the moist evergreen. Luminance levels range from 30 to 60 footcandles during the wet season and 125 to 200 footcandles during the dry season. Illumination levels have little or no effect on horizontal target detection. The potential importance of illumination in the semideciduous forest is neutralized by the effect of obscurative eyelevel vegetation.

*TECOM Test Operations Procedure 1-1-054, Ground-to-Ground Target Detection in Tropic Forests, USATTC March 1974.

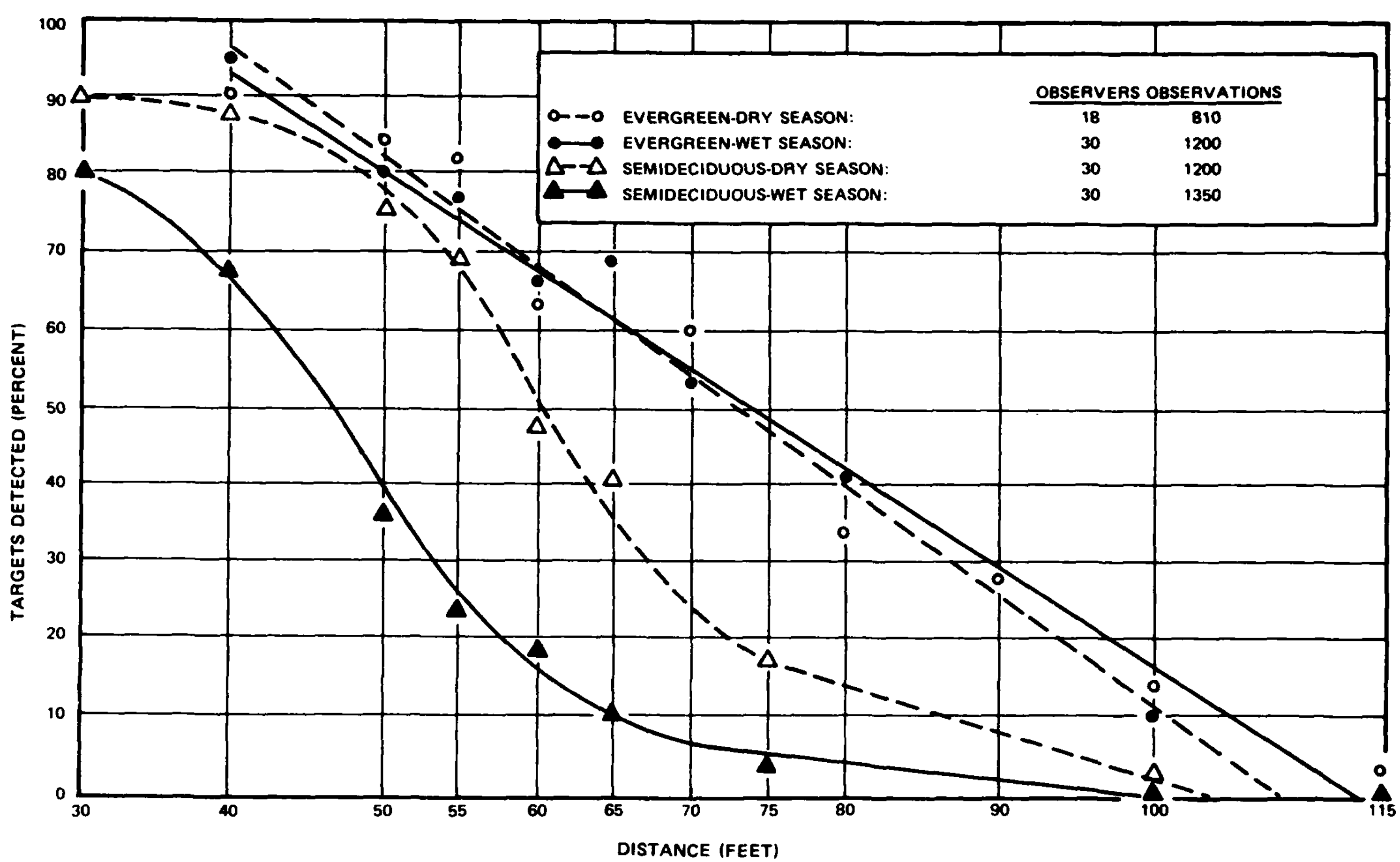


Figure X-6. Visibility Gradients for Single, Standing Human Targets on the Same Evergreen and Semideciduous Tropic Forest Sites during Dry and Wet Seasons. For Each Condition, Subjects Viewed Stationary Human Targets Randomly at Varying Distances over a 180°-Field of View.

An early study of target detection in semideciduous forests by Austey and Stiles (1963) was conducted as a part of the Swamp Fox II exercise during the wet season. The test design differed from the above studies in that the observers walked through the forest toward the target soldiers. Target soldiers wearing the standard US Army fatigue uniform, shade OG 107, with the standard field cap were prepositioned in the jungle before the observer was brought to the site, and were instructed to remain standing erect and motionless, until detected by the observer. A variety of sites, randomly distributed throughout the jungle, were used in this study. With this technique detection distances were reduced over those using stationary observers. The median detection distance for a series of trials was 21.5 feet (6.6m), with many detection distances fewer than 10 feet (3m) and only 2 percent over 50 feet (15m).

Dobbins and Kindick (1966) showed that some standard visibility objects (SVO) yield detection data similar to the results yielded by human targets, while other SVO yield dissimilar detection data. Olive drab silhouettes and olive drab cylinders are interchangeable with human targets; however, the frequently used single and double visibility Secchi discs are not interchangeable (table X-2).

Table X-2. Detection Ratios for Human Targets and Standard Visibility Objects.

Mature Evergreen Rainforest Sites

Type Target	Site V	Site W	Total (Both Sites)
Human Target	51.2%	46.0%	48.3%
OD Silhouette	49.4%	50.0%	49.7%
OD Cylinder	45.7%	54.0%	50.0%
Double Disc	45.1%	59.6%	53.1%
Single Disc	37.7%	50.5%	44.7%
Camouflaged Silhouette	43.8%	41.4%	42.5%

Dubuisson and Kindick (1971) conducted tests during both wet and dry seasons and found that average detection distances with walking human targets in the semideciduous forest ranged from 50 to 55 feet (16-17 m). This detection range is slightly greater than with the standing human targets. Walking targets wearing black Viet Cong garb were as easily detected as those wearing the standard fatigue uniform. None of the walking targets were detected beyond 110 feet (34m) (figure X-7).

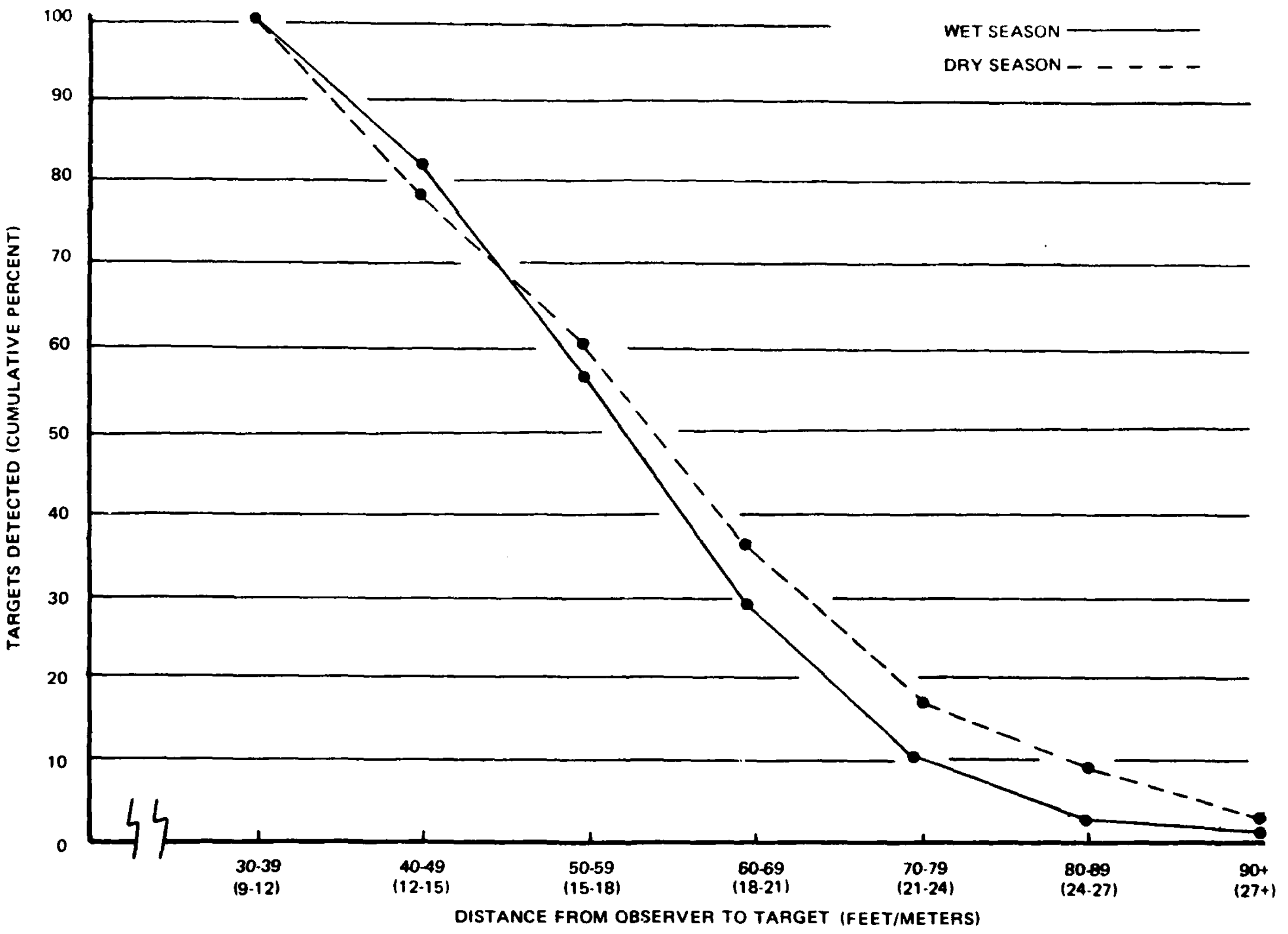


Figure X-7. Comparison of Visibility Gradients for Walking Human Targets (in OD Fatigues or Black Pajama-Type Clothing) Which Appeared Randomly over a 180° Field of View (Daytime).

Night Vision in the Jungle

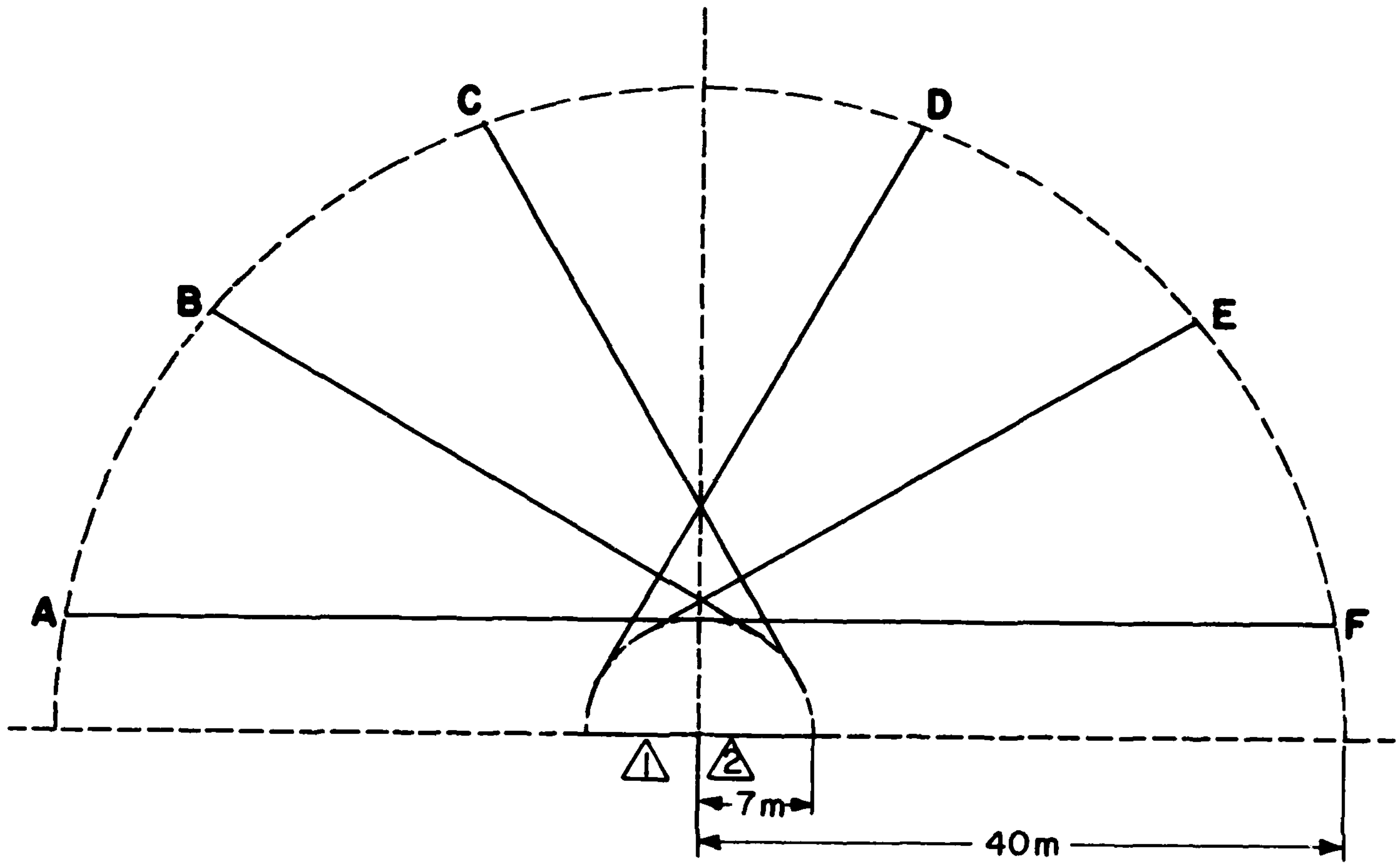
In a series of tests, USATTC compared the target detection performances of several night vision devices with each other and with unaided vision (Chura, et al., 1976). The tests were conducted during daylight (to provide a reference standard of performance), and at night under moonlight. The night vision devices tested were the Hand-held Thermal Viewer (AN/PAS-7) and two light amplification devices: The Night Vision Sight for Crew Served Weapons (AN/TVS-5) and the Night Vision Sight for Individual Served Weapons (AN/PVS-4). The tests were conducted on a ground-to-ground target detection course illustrated in figure X-8. In these tests a two-man observation team searched a 180°-sector of jungle, each observer attending to a quadrant. The night vision devices were all tripod-mounted. On each trial, a target soldier dressed in jungle fatigues walked along one of the target paths toward the observer until he was detected. At that point target detection distance was obtained. Test conditions are shown in table X-3. Table X-4 presents the distances at which the average soldier has 100-percent, 50-percent and 0-percent chances of detecting a moving target soldier under the various test conditions.

Table X-3. Test Conditions for Evaluation of Night Vision Devices.

Data Points	Test Conditions	Horizontal Illuminance (footcandles)
18	Day, unaided vision	6.0×10^{1}
18	Day, AN/PAS-7	6.0×10^{1}
36	Night (moonlight), unaided vision	6.0×10^{-5}
18	Night (moonlight), AN/PAS-7	6.0×10^{-5}
18	Night (moonlight), An/TVS-5	8.4×10^{-4}
18	Night (moonlight), AN/PVS-4	8.8×10^{-5}

Table X-4. Detection Distances (Meters) for Moving Target

Test Conditions	Probability of Visual Detection		
	100%	50%	0%
Day, unaided vision	4	19	40
Night (moonlight), unaided vision	1	6	20
Night (moonlight), AN/PAS-7	3	16	35
Night (moonlight), An/TVS-5	1	6	10
Night (moonlight), An/PVS-4	1	7	14



A-F : TARGET LANES

△ : OBSERVER POSITIONS

Figure X-8. Ground-to-Ground Target Detection Test Site.

The two light amplification devices produced approximately the same detection results at night; therefore, only the AN/TVS-5 results are compared with AN/PAS-7 results in figure X-9. The AN/TVS-5 showed no better detection performance than the unaided eye in night operations, indicating that light amplication devices are not suitable for jungle use. The AN/PAS-7 exhibited a significant improvement over the unaided eye in night jungle use. The poorer performance under daylight conditions was attributed to higher thermal background levels which produced lower contrasts.

On the basis of the above data the AN/TVS-5 and AN/PVS-4 are not suitable for jungle operations.

Night Vision From Jungle to Road

As a part of the night vision device tests (Chura, et al., 1976), USATTC conducted a special study to determine the usability of the AN/PAS-7 for maintaining surveillance of a jungle road by an observer positioned inside the jungle. The objective was to determine the effectiveness of the AN/PAS-7 as compared with the unaided eye.

A test site was established in the jungle adjacent to a narrow road (4 meters wide with a cleared shoulder area of 3 meters). The site consisted of four observation stations at distances of 10, 15, 20, and 30 meters from the edge of the road. Four separate tests were conducted under the following conditions:

Number of Data Points	Time Of Day	AN/PAS-7 Used	Illuminance (footcandles) Road	Illuminance (footcandles) Observation Station
96	Night	Yes	6.0×10^{-5}	1.0×10^{-5}
96	Night	No	6.0×10^{-5}	1.0×10^{-5}
96	Day	Yes	1.5×10^{3}	6.0×10^{0}
96	Day	No	1.5×10^{3}	6.0×10^{0}

During data collection, a series of targets moved along the road. The targets were: a single soldier walking, a group of three soldiers walking, a 1/4-ton vehicle, and a 5/4-ton vehicle. Targets passed by the observation site spaced about 50 meters apart in random order from one trial to the next. Table X-5 shows the number of observer detections of personnel or vehicles on the road (D), recognitions of either personnel or vehicles (R), and identifications of vehicle type (I), D=D+R+I, R=R+I out of a possible maximum of twelve.

The data above and the curves in figure X-10 show perfect personnel recognition and vehicle identification up to 30 meters during the day with normal vision, and near zero detectability at night with normal vision. The AN/PAS-7 worked equally well for all target types and lighting conditions. It proved more effective than the unaided eye during night operations.

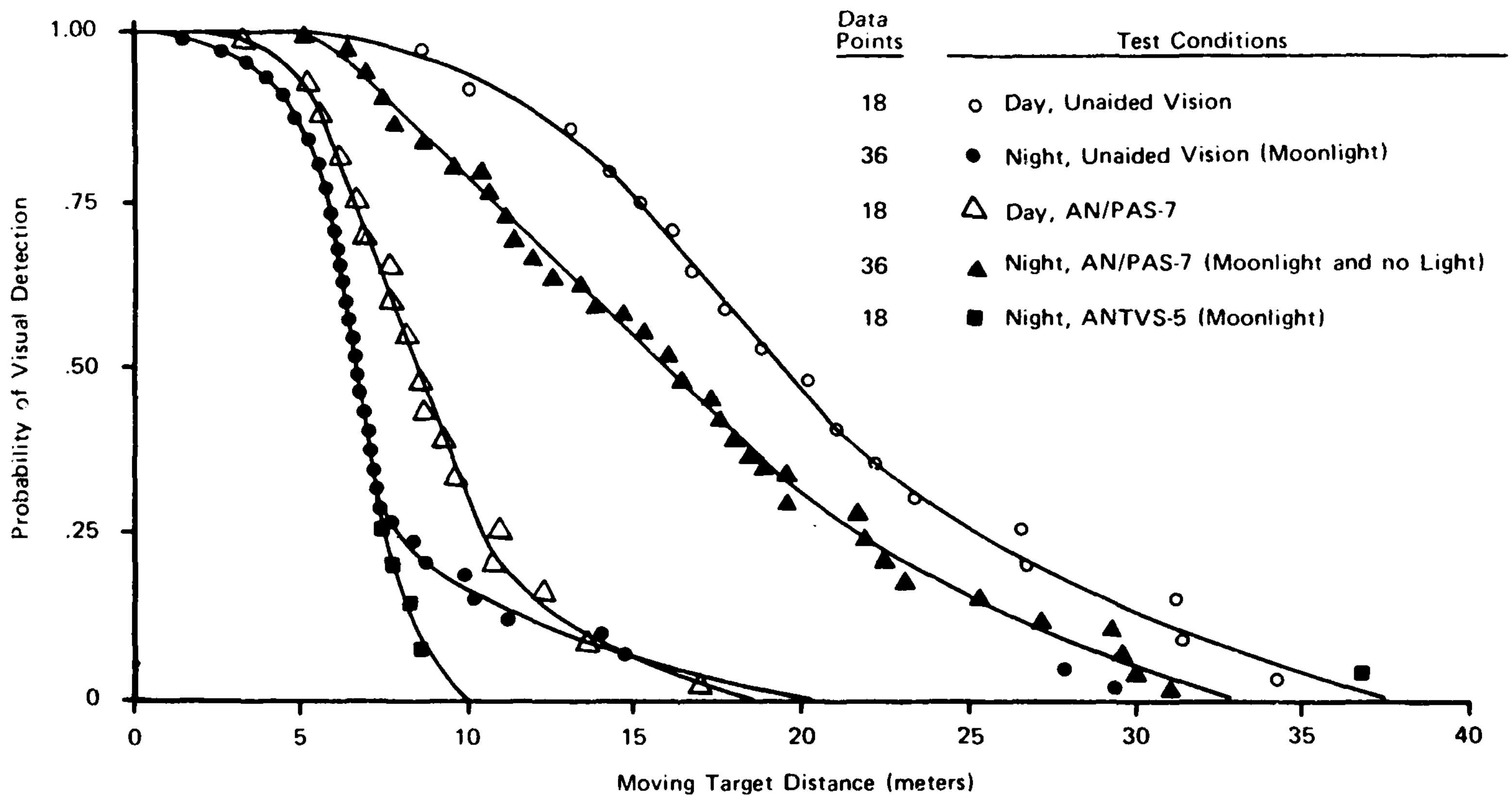


Figure X-9. Probability of Visual Detection of a Moving Human Target in the Jungle, by Distance of Target from a Two-Man Team Searching a 180^{0}-Sector.

Table X-5. Observer Detections, Recognitions, and Identifications for the AN/PAS-7 in Jungle to Road Operations

	Daytime									
	AN/PAS-7					Unaided Eye				
Meters	Personnel		Vehicles			Personnel		Vehicles		
	D	R	D	R	I	D	R	D	R	I
30	0	0	2	0	0	12	12	12	12	12
20	7	6	8	7	3	12	12	12	12	12
15	6	6	9	8	3	12	12	12	12	12
10	11	9	12	9	4	12	12	12	12	12
Total	24	21	31	24	10	48	48	48	48	48

	Nighttime									
	AN/PAS-7					Unaided Eye				
Meters	Personnel		Vehicles			Personnel		Vehicles		
	D	R	D	R	I	D	R	D	R	I
30	2	2	7	4	0	0	0	0	0	0
20	6	6	6	4	1	0	0	0	0	0
15	10	10	11	11	7	0	0	0	0	0
10	11	11	12	10	3	1	0	4	4	1
Total	29	29	36	29	11	1	0	4	4	1

LEGEND: D - Detections
R - Recognitions
I - Identifications

The data provided the same recommendations for use as the study conducted entirely within the jungle: During the day--unaided eye; at night--the AN/PAS-7; at dawn and dusk--both. The AN/PVS-4 and AN/PVS-5 were tested under the same conditions but gave results no better than the unaided eye.

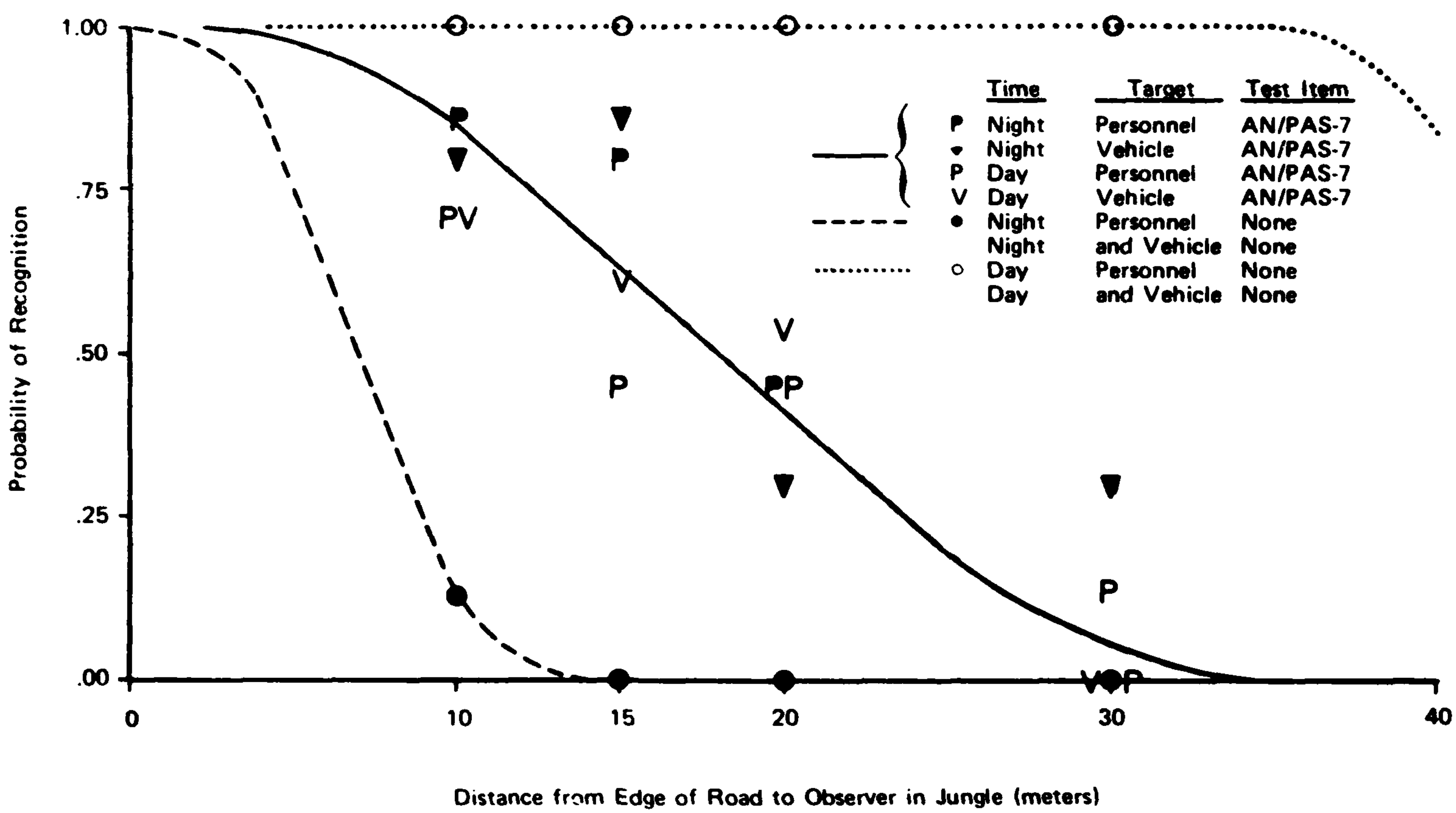


Figure X-10. Probability of Recognizing Targets Moving on a Road by Distance of Observer in Jungle.

SECTION XI. HUMAN FACTORS IN THE TROPICS

A. INTRODUCTION

Human Factors is often confused with human engineering, but the terms have different meanings. Human engineering deals with the design of machines, procedures and work environments so that they match or complement human capabilities limitations. An example of human engineering would be the design of the controls and workspace in an armored vehicle so that operator proficiency is maximized and driver error, fatigue and discomfort are minimized. By contrast, human factors is a broader field which involves a wide variety of human and external variables that motivate, modify, limit, or somehow affect human behavior. Examples of human variables include intelligence, aptitudes, physiological factors, personality and physical strength. Examples of external variables include heat and humidity, noise, vibration, jungle vegetation and adverse terrain.

In most cases human factors evaluations made in the tropics are concerned with external variables, because the evaluations deal with a preselected group of men (soldiers) who have met or exceeded minimum intelligence, aptitude, performance and physical standards. Primary interest is in determining both soldier-item-activity proficiency and equipment acceptance when subjected to the humid tropic environment. The US Army Human Engineering Laboratory at Aberdeen Proving Ground, Maryland, is the primary research organization in the field of human engineering. USATTC conducts suitability tests, except in cases of production urgency or commercial development when equipment has bypassed the normal RDTE cycle.

B. ENVIRONMENTAL EFFECTS ON MAN IN THE TROPICS

Psychological Adjustments

R. D. Pepler (1963) reported that British civilians and military personnel did not react in the same manner to living in tropics. He postulated that the difference may be due to selection procedures and psychological adjustment. Civilians were generally in the tropics by choice and were free to set their own life styles, whereas military personnel stationed in the tropics had no choice in being there and generally regarded their stay as a hardship to be endured. The climate was regarded as only one of many sources of irritation. Nevertheless, many civilians reported higher incidence of vague illnesses, sapped energy, and malaise near the end of prolonged tours in the tropics. Brief visits to temperate environments were reported to "rejuvenate" many tropic dwellers. The basis for this may have been either psychological or physiological. Naval personnel living

aboard ships in the tropics carried much of their environment with them in the form of life aboard the ship itself. They experienced an increased sickness rate and increased feelings of lassitude and irritablility.

Pepler reported that long-term psychological adjustments to tours in the tropics are to be expected. The general stability of the climate in the tropics and the relatively constant stimulation of the skin by heat may contribute to feelings of lassitude and fatigue. It is probable that lack of efficiency in the tropics may result from changes in endocrine balance, basal metabolism rate, or in salt and water balance.

Performance in Chambers versus Natural Tropics

Pepler (1958) compared human performance in a heat chamber with human performance in the natural tropics. In Singapore he carried out experimental field replications of research which had been done in heat chambers at Cambridge. Subjects performed tracking, vigilance and decision-making tasks in both studies. Pepler states, "The results of the experiments at Singapore confirmed to a large degree the principal findings on artificially acclimatized men. The performance of naturally acclimatized men generally deteriorated over the same range of effective temperatures as did the performances of the artificially acclimatized men, i.e., performance deteriorated between climates with effective temperatures of 81°F and 86°F (27°C and 30°C)." However, the author noted some differences in performance between the two groups. Personnel living in the tropics did not perform as effectively as those in England under the cooler conditions--an effect that he attributes to long-term acclimatization.

A survey by Harris and O'Hanlon (1972) of the US Army Human Engineering Laboratory concluded that the evidence is strong that one cannot generalize from performance in the laboratory to real tasks. They pointed out that many military tasks are so well learned that they risk decrement. Complex tasks that are likely to be affected by environmental stress include decision making and vigilance. Stress factors in a field situation tend to occur together and not in isolation as in the laboratory. For example the soldier may be thirsty, tired, angry, hot and sleepy all at the same time. These combinations will definitely affect work/rest and performance/recovery schedules more than would typical laboratory studies.

Acclimatization

Lack of acclimatization was shown by a group of F-104 Air Defense test personnel who departed Rhode Island for the Canal Zone in winter weather and arrived to be confronted with high temperatures and relative humidity. Several persons suffered heat exhaustion and sunburn,

and duty hours had to be rearranged so that work was done in the early morning and in the late afternoon and early evening.

Problems with acclimatization were also encountered during Operation Banyan Tree II, which was a combined military operation involving United States, Columbian, Peruvian and Brazilian forces in simulated combat maneuvers in the Rio Hato area of the Republic of Panama (US Army Caribbean Command, 1962). There were numerous heat casualties on the first day of the operation, even though the troops involved in the operation had had a 2-day training course at the Jungle Warfare Training Center in the Canal Zone prior to combat maneuvers. It was recommended that in actual operations involving long distance moves from different climatic areas, prior training should be conducted to acclimatize participating troops.

The US Naval Medical Field Research Laboratory conducted a study to determine the optimal time for acclimatization to wet-hot conditions (Garden, et al., 1965). Performance tests and physiological parameters were used. Thirty-eight young adult males were exercised daily for 2 weeks on a motor driven treadmill at 3.5 (5.6 kilometers-per-hour) miles-per-hour with in a heat chamber maintained at 98°F (37°C) dry-bulb and 90°F (32°C) wet bulb (73% relative humidity). Twelve subjects walked for 50 minutes followed by 10 minutes rest in the heat; 13 subjects walked 50 minutes, rested 10 minutes, walked 30 minutes and rested a final 10 minutes; 13 subjects walked 50 minutes, rested 10 minutes, walked 50 more minutes and rested a final 10 minutes. A modified Balke performance test was administered before heat exposure and at the end of each week. Physiological measures including rectal temperature, heart rates, sweat loss and sweat electrolytes were used as measures of acclimatization. Under conditions of this study, the optimal time for acclimatization to hot-wet conditions was between 60 and 90 minutes of daily exposure over a period of 9 days.

Heat Stress

The Wet-Bulb Globe Temperature (WBGT) index that proved helpful in reducing heat casualities of military personnel in the southeastern United States has been measured at both ends of the Canal Zone for many years. Table XI-1 presents percents of WBGT measurements that reached or exceeded critical WBGT levels. The months chosen represent the dry, transitional (April and May), and wet seasons, respectively. The table shows that the critical values are more often exceeded on the Atlantic side of the Isthmus than on the Pacific side. The absolute maximums of the entire year were 101°F (38°C) at Fort Sherman and 98°F (37°C) at Chiva Chiva. The highest values were measured immediately before the onset of rain and in the two seasonal transitions--dry-wet and wet-dry. The frequencies for hours other than those shown are similar for neighboring hours and drop off sharply towards sunrise and sunset. From 1900 through 0700 hours, less than

one-half percent of all WBGT measurements exceeded 85°F (29°C). For test scheduling, it is clear that the Atlantic side presents a more severe heat-stress environment for test troops than the Pacific side.

Table XI-1. Percent of Measurements Equaling or Exceeding Critical Values of the WBGT Index[a]

Critical WBGT:	Atlantic Side[b] 85°F (29°C)	88°F (31°C)	Pacific Side[c] 85°F (29°C)	88°F (31°C)
February	84[d]	63[d]	41[e]	10[e]
April	85[e]	65[e]	--	--
May	77[f]	54[e]	61[f]	22[f]
November	62[e]	41[e]	48[f]	20[f]

a Based on 8 to 10 years of observation
b Fort Sherman Shelter Point and Fort Sherman Open Field site combined
c Gun Hill and Chiva Chiva Antenna Farm combined
d At 1300 hours
e At noon
f At 1100 hours

The Human Engineering Laboratory conducted studies during the Swamp Fox II operation (Woodward, 1964) to determine the effects of high level thermal stress on personnel. Hourly data were collected on air temperature, humidity, air movement, solar radiation and wet-bulb globe temperature index. Military subjects in two groups, infantrymen and enlisted specialists, were studied while walking on a course laid out on a hill slope of 12.5 degrees. Measurements of body temperature, heart rate, and sweating were used as indices of thermal stress during the walking periods. Substantial thermal stress was experienced by all subjects, but no intolerably severe strain was observed. Measurements of sweat production and sweat evaporation were primarily a function of walking speed, and showed little relation to variations in the thermal environment. The heat absorbed by sweat evaporation appeared to be of the same order of magnitude as that produced by the work of walking the hill course. Measurements of pulse rate showed that the steady state level, achieved in all but one instance, was a function of walking speed and showed little relation to variation in the thermal environment. Measurements of average body temperature did show correlations between the physiological behavior of the men and variations in the thermal environment. Changes in body temperature followed in many cases within a few minutes upon environmental changes, particularly those due to variation of solar radiation and to air movement. The level of solar radiation is a primary factor in determining the severity of the total human thermal environment.

In addition, measurements were made of combat-relevant performances (choice-reaction time, hand-steadiness, equilibrium and running

speed) of 11 infantrymen before and after sustained confinement (up to 6 hours) in an M-113 Armored Personnel Carrier exposed to the tropic sun. Results showed statistically significant losses in hand-steadiness, equilibrium and running speed, but there was a low risk of heat casualties among men confined in the M-113 APC. Oral temperatures and pulse-rate changes indicated that the men could easily tolerate exposures to 92°F (33°C) effective temperature for as long as 4 hours.

Jones (1970) of the Human Engineering Laboratory surveyed the literature on heat stress and human performance. He found some studies in which performance decrements were induced by high heat and humidity, others where there was either no effect or performance improved. Conflicting results were attributed to problems in the prediction of performance decrement as opposed to physiological declines, differing lengths of exposure, heterogeneous test subjects, poor control of the thermal environment, and extraneous variables that creep into laboratory studies. Laboratory studies were criticized as: being poor approximations of nature, selecting only a limited number of independent variables, using artificial and unrealistic performance measures, and ignoring motivation problems dealing with the test subjects' expectations and distrust of the possibly hidden purposes of the experiment.

Personnel Hazards

The tropic environmental effects on Army materiel and its use extend beyond direct damage to the test item. Organisms attracted to storage facilities and test items or those generally present in the immediate environment often present hazards to personnel retrieving and using test items. These hazards range from major health dangers to a minor source of irritation and are generally more prevalent and diverse in the tropics than in other environments.

Snakes. Although snakes are numerous in Panama in terms of both number and species, their nocturnal habits and general fear of man make them a relatively minor threat. Storage areas, however, frequently provide convenient shelter for snakes during the day. For this reason extreme caution must be exercised when retrieving samples, expecially those stored under tarpaulins. Panama has five terrestrial poisonous snakes extremely hazardous to man. The most common of these is the fer-de-lance which accounts for more snakebites in Panama than all other poisonous snakes combined. There is also the bushmaster, the largest poisonous snake in the western hemisphere; the hog-nosed and palm vipers, small grassland and shrub-dwelling species; and the coral snake, a small-mouthed venomous snake rarely biting man.

Insects. Of the discomforts and dangers affecting man in the tropics, insects are the most serious. They may act only as simple irritants or as carriers of serious tropical diseases. Stinging and biting insects (wasps, bees, scorpions, centipedes, spiders) are frequently

found associated with exposed test items and in many cases they build nests within the item. Contact with these insects can result in a variety of responses from minor itching to painful sores and infections. In allergic, sensitive individuals, even death may result. Finally, a number of tropic insects, including mosquitos, ticks, sandfleas, sandflies, and "assassin" bugs, carry serious diseases such as malaria, yellow fever, leishmaniasis, and the rare Chagas disease.

Fungi. Fungi can affect man as either pathogens or allergens. Since fungi flourish in tropic environments they sometimes act as health hazards to personnel, expecially in enclosed areas. For example, long unused ammunition bunkers, when inhabited by bats are a source of a serious lung fungus, Histoplasmosis. Large test items meant to harbor men and materiel may accumulate high enough levels of fungal activity to endanger personnel using the item.

C. MAN-MATERIEL EFFECTS

Vehicles--Tracked and Wheeled

The primary considerations for this class of materiel include heat build-up in compartments where personnel will be confined, noise levels, illumination levels, and presence or absence of noxious gases. Ease of entry and exit is an important factor, especially in relation to Armored Personnel Carriers. Visibility is also a factor to be considered for drivers and crew because the warm, humid tropic environment often creates a considerable amount of condensation on windows and optics.

Several problems relating to human factors engineering were encountered during the Swamp Fox II operation. Riding over difficult terrain, especially in vehicles with large diameter tires, caused abnormally rapid driver fatigue. Complete lack of protection against mud and debris thrown by the front driving wheels of the 1/4-ton truck, M151 and the XM520 caused discomfiture to vehicle drivers. Similar lack of protection against tree branches and other terrain hazards for operators of open-cab vehicles and scooters reduced driver efficiency. Heavy vegetation can also serve to obscure visibility to the point where maneuverability is greatly hindered. In a USATTC test of a Liquid Distributor for Dust Control (Jennings, 1974), human factors problems encountered were steering wheel pull of 4 pounds (2 kilograms) which was below the 5- to 50-pound (2- to 23-kilograms) criterion, and complaints by pilot and crew of lack of visibility of ground pad surface caused from glare.

Whenever possible, testing is conducted during both wet and dry seasons because the amount of solar radiation, humidity and rainfall varies. Measurements of internal compartment temperatures are made under operational conditions extending over a period of several hours

to record the various tropic conditions. For armored vehicles, measurements are made with hatches both closed and open. Temperature readings without crew and personnel do not represent an accurate operational test because both personnel and machinery contribute significantly to overall internal heat which can, and has, overcome the ventilation capabilities of vehicles.

An abbreviated product improvement test of the D7F Tractor was conducted by USATTC (Giordono, 1976). The climatized cab was evaluated for comfort and noise level. During the dry season and also during the month of May (a transitional period between wet and dry seasons) temperature and relative humidity data were taken both inside and outside the cab. A comfort evaluation comparison was made between the test system and a D7F without a cab. It was found that during both seasons the air conditioner used inside the cab had no more effect than a fan providing the same air velocity with the cab open. Noise level inside the cab was measured with an octave band analyzer by placing a microphone 4 inches from the operator's right ear. An attendant monitored the recording system while the tractor was operating. It was found that the climatized cab with air-conditioning provided a significant reduction in noise level compared with the tractor without a cab; however, noise reduction was not sufficient to insure safe operation without hearing protection.

Randall (1966) evaluated an olive drab enamel that reflected solar heat. Temperatures were measured at five different locations in and on two M113 Armored Personnel Carriers--one painted with the heat-reflecting enamel (CCL No. 613-431, supplied by the US Army Coating and Chemical Laboratory) and the other with conventional lusterless olive-drab finish (Federal Standard 595#34087). Over a 5-day period, measurements in and on each APC showed that temperatures were always lower in the vehicle with the reflecting paint, with maximum differences at the five different locations ranging from 3.5°C to 7.0°C. Because this paint reduces the temperature of the vehicle skin and the air in the crew compartment, it would reduce the thermal stress on personnel inside the vehicle. If this paint were used with air-conditioned vehicles, it would reduce air conditioning requirements.

Aircraft

Human factors problems have been found in the operation of aircraft in the humid tropics. Army medical reports from Southeast Asia indicated that Army aviators experienced difficulties from heat stress induced by high cockpit operating temperatures. As reported, these difficulties were primarily physiological in nature. Crews flying the fixed-wing OV-1 (MOHAWK) complained of discomfort, fatigue, and other symptoms indicative of mild heat exhaustion. The same report was made of the rotary-wing AH-1G (COBRA). Pilot proficiency was reduced during extended periods of flight in direct sunlight--especially in the

hot dry season. Pilots were subject to vision problems resulting from perspiration, exhaustion and dehydration after extended periods of flying.

The Human Engineering Laboratory conducted an exploratory study (Moreland, Barnes, 1970) of pilot performance during conditions of high temperature and humidity at Fort Rucker, Alabama, in 1970. The purpose was to measure performance changes which may occur when army personnel, wearing complete operational combat flight clothing and equipment, fly Light Observation Helicopters in hot humid weather. It was found that pilot performance deteriorated and performance variability increased above a WBGT index of 85°F (29°C). Pilots' reaction times increased as either ambient temperature or rectal temperatures increased. Large differences in performance variability among pilots were due to differences in pilot techniques (regardless of experience).

Vans and Shelters

This equipment consists of communication vans, protective shelters, tents, field kitchens and multi-purpose structures that may or may not be mobile, but are designed to remain in one location over relatively long periods of time.

The human factors areas to be investigated include heat, air flow, humidity, noise and illumination levels. For portable structures, ease of setting up and taking down are major considerations. Temperature measurements are obtained with operating personnel inside the structure and with all operational instrumentation turned on. The classic tropic problems of high heat, high humidity, and low air movement often combine to cause intense discomfort and intolerable working conditions. In a Special Forces base radio station test (USATTC, 1964), air temperatures approached 100°F (38°C) in a communications van. Figure IX-1 shows the relationship between temperature and comfort. In testing a Mobile Field Kitchen Trailer (Schoonover, 1975), it was reported that internal air temperature rose to an extreme value of 207°F (97°C) at a height of 6.5 feet, (2.0 meters) from the floor, making it impossible for personnel to remain in the structure. Table IX-2 shows temperature data for the kitchen. Figure IX-2 shows the 5.0-ft. (1.5m) data placed on the thermal tolerance and comfort zone chart found in MIL-STD 1472B.* Some data above the 5.0 ft. level (1.5m) are beyond the boundaries of the chart.

Clothing and Personal Equipment

Among the major items in this category are fatigues, helmets, caps, boots, gloves, protective gear, mess gear, sleeping gear, goggles, backpacks and entrenching tools. For most equipment in this category,

* MIL-STD 1472B, Human Engineering Design Criteria for Military Systems Equipment and Facilities, 31 December 1974.

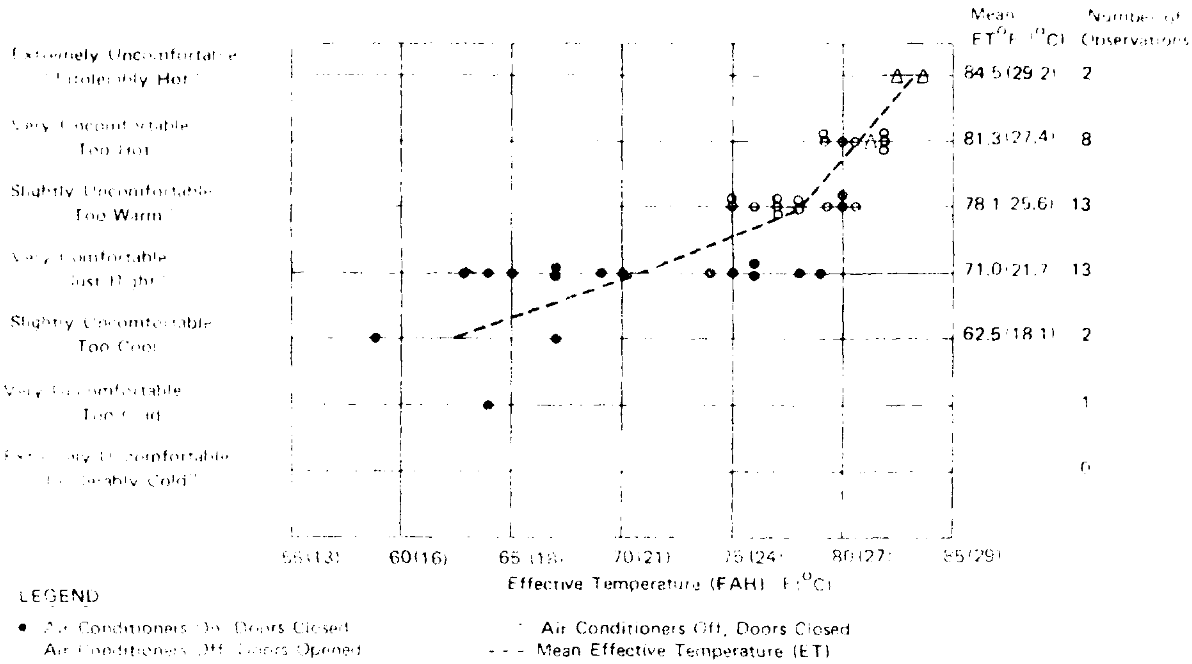


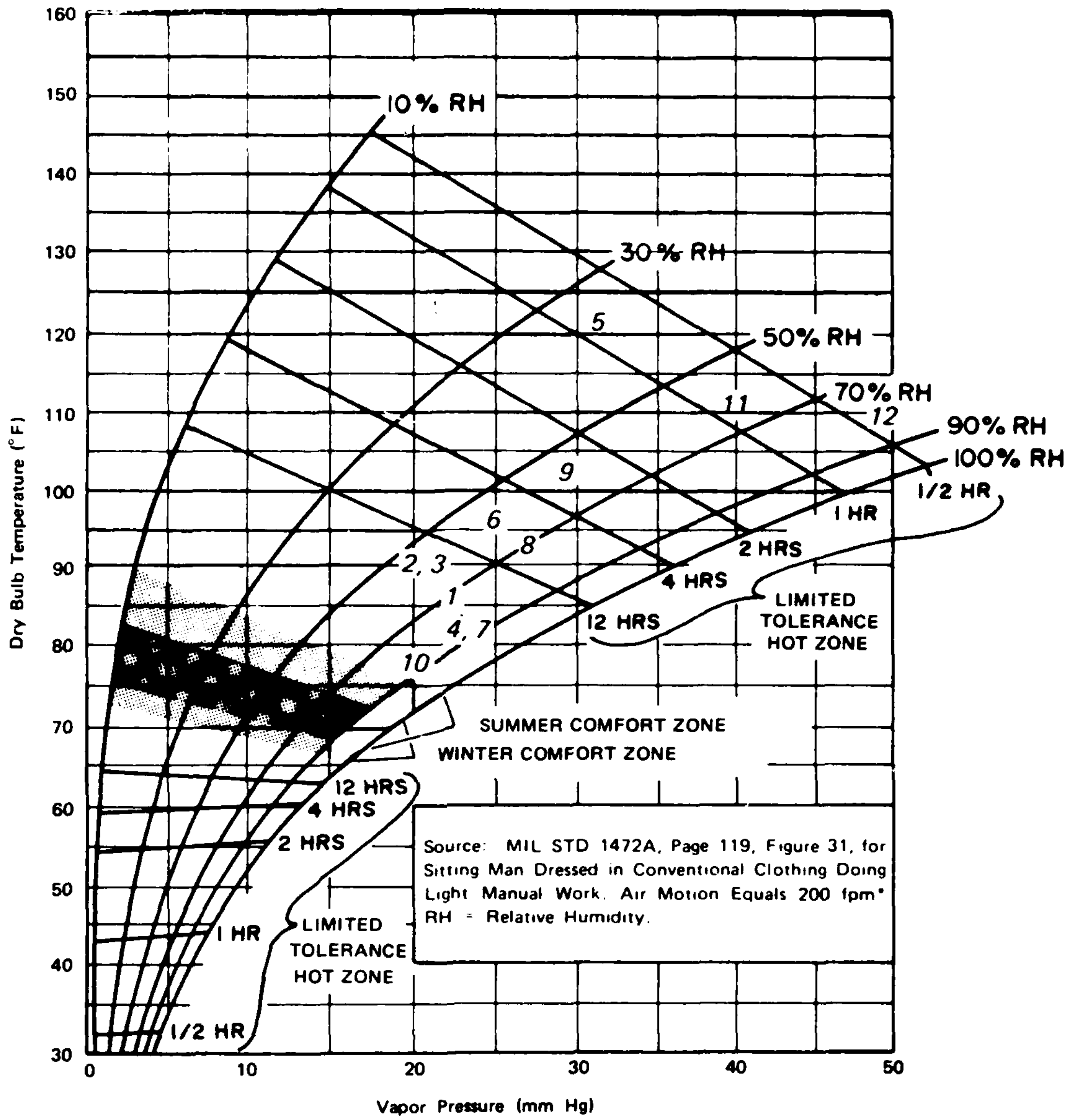
Figure XI-1. Relationship between Effective Temperature and Rated Comfort in Base Radio Vans.

Table XI-2. Vertical Temperature Profile during Tropic Operation for 12 Operation/Configuration Combinations* of Mobile Field Kitchen.

	Temperature (°F (°C) by Kitchen Configuration)			
Distance from Floor	Open	Modified Foul Weather	Foul Weather	Blackout
Burners Off				
6.5 (2.0)	†	83 (28)	85 (29)	81 (27)
5.5 (1.7)	84 (29)	81 (27)	85 (29)	80 (27)
5.0 (1.5)	(87) (31)	(82) (28)	(82) (28)	(78) (26)
	(RH = 71)	(RH = 84)	(RH = 88)	(RH = 87)
3.0 (0.9)	84 (29)	80 (27)	83 (28)	80 (27)
1.5 (0.5)	84 (29)	79 (26)	85 (29)	79 (26)
0.5 (0.2)	83 (28)	79 (26)	86 (30)	80 (27)
Burners on Approximately 1 Hour				
6.5 (2.0)	†	154 (68)	152 (67)	197 (92)
5.5 (1.7)	111 (44)	135 (57)	123 (51)	172 (83)
5.0 (1.5)	(90) (32)	(120) (49)	(94) (34)	(110) (43)
	(RH = 58)	(RH = 38)	(RH = 69)	(RH = 65)
3.0 (0.9)	92 (33)	83 (28)	93 (34)	102 (38)
1.5 (0.5)	91 (33)	80 (27)	80 (27)	91 (33)
0.5 (0.2)	91 (33)	80 (27)	90 (32)	90 (32)
Burners on Approximately 2 Hours				
6.5 (2.0)	†	121 (49)	145 (63)	151 (66)
5.5 (1.7)	105 (41)	101 (38)	116 (66)	141 (61)
5.0 (1.5)	(89) (32)	(96) (36)	(102) (38)	(110) (43)
	(RH = 60)	(RH = 61)	(RH = 60)	(RH = 75)
3.0 (0.9)	95 (35	87 (31)	89 (32)	90 (32)
1.5 (0.5)	95 (35)	84 (29)	87 (31)	86 (30)
0.5 (0.2)	95 (35)	83 (28)	84 (29)	84 (29)

* Each temperature shown is the mean of three data points at the designated distance from the floor, except for 5'0" data. Temperatures in each of the 12 operation/configuration profiles are based on data obtained at the same instant, except the 5'0" data. The 5'0" data (dry bulb temperature and relative humidity (RH)) were obtained within a few minutes of the other data (at center of kitchen only) and are therefore in parentheses because they cannot be expected to fit the trend of the other data exactly.

† Data not obtained.



* Air velocity criterion equals 200 fpm for tolerance zones and 20 fpm for comfort zone; kitchen air velocities were between 28 and 104 fpm.

Operational Time	Chart Location for Kitchen Configurations: Open	Modified Foul Weather	Foul Weather	Blackout
Before lighting burners	1	4	7	10
After 1 hour—burners on full	2	5	8	11
After 2 hours—burners reduced (except open configuration)	3	6	9	12

Figure XI-2. Kitchen Temperature and Humidity 5 Feet (1.5 meters) from the Floor Compared to Thermal Tolerance and Comfort Zone Criteria.

objective data are gathered by use of the USATTC Man-pack Portability Course and associated performance decrement measures described in paragraph D of this Section. Troop acceptance is determined by subjective questionnaires administered to user troops and through checklists completed by test personnel. Visual camouflage questions are answered by using a ground-to-ground target detection range established in the jungle.

Important factors to be considered are degree of overall comfort, adequacy of ventilation, capability of garments to absorb and release moisture and perspiration, ease of donning and doffing, adequacy of fit, lack of hindrance (snagging or binding) when entering or exiting vehicles and vans, and degree of freedom from snagging or catching when worn in heavy vegetation. For various types of headgear, vision should not be impaired.

An example of a clothing hazard not discovered until tropic service testing was the interaction of the jungle boot with the entrance steps of the Mobile Field Kitchen Trailer. The large cleat of the jungle boot of troops sank into the wide spaces of the metal stairs of the kitchen causing the wearer to trip and occasionally fall when descending. An expanded metal screen was secured to each step, reducing the size of the holes while still providing traction for the muddy jungle boot tread.

Portability and usability are key factors for consideration. For man-packed items, freedom from excessive snagging on vegetation, overall weight and its distribution, and physical comfort are important factors. Hand tools should provide proper leverage and should not pinch, bind, or create blisters when used for a reasonable length of time (e.g., time taken to dig a foxhole or prone shelter with an entrenching tool). Goggles and protective masks should be tested under conditions of high humidity to determine whether accumulation of condensation on glass or plastic surfaces hinders vision. Tropic sleeping gear should be tested for heat build up, ease of entry or exit and rated survival value.

USATTC conducted a tropic service test of a Lightweight Intrenching Tool (Curtis, Vaughn, 1969). In spite of some superior features of the test item, deficiencies such as lack of effectiveness in digging and poor design caused user fatigue and irritability. The tool was not durable and there was no "pick" device, a desirable feature of the Standard Intrenching Tool. USATTC recommended that the Lightweight Intrenching Tool not be considered a suitable replacement for the Standard Intrenching Tool.

In 1963, the Army Research Institute for Environmental Medicine and the Combat Developments Experimentation Command conducted a study in the Canal Zone to determine whether combat operations could be

carried out in the humid tropics by men dressed in chemical-biological-radiological protective uniforms (Joy, Goldman, 1968). By the end of 2 hours of tactical exercises (e.g., attack, dig in, defense), over 50 percent of the troops, both acclimatized and nonacclimatized, were heat casualties with reactions such as fainting, cramps, vomiting, mental confusion, physical collapse, and temperature failures (those whose rectal temperatures rose to 103°F (39°C)). Casualties occurred whether the suits were worn closed or open. The study was conducted in open terrain during the dry season. Wet-bulb globe temperatures ranged from 82°F (28°C) to 87°F (31°C).

In 1968, USATTC conducted a test (Jurczak, Vaughn, 1969) to determine the suitability of the armored vehicle crewman's uniform for use by the US Army in a natural tropic environment. It was tested by personnel representative of those who would normally wear the uniform in the course of duty. The major finding in this test was that the uniform was so uncomfortably hot that troop acceptance was very low. This was considered a deficiency, and therefore the uniform was considered unsuitable for use in humid tropic environments.

In November of 1975, the XM29 mask was tested for suitability of use on a jungle patrol where temperature was 83°F (28°C), relative humidity was 85-percent, and air movement was less than one mile per hour. The masks fogged, collected sweat, and could not be worn by some troops for more than 20 minutes (Novack, et al., 1976).

Between September 1977 and January 1978, the Personnel Armor System for Ground Troops (PASGT) was tested (DT II) at USATTC (Haverland, et al., 1977; and Johnson, Haverland, 1978). The PASGT consisted of a fragmentation protection vest with a ballistic filler of 14-oz/yd^2 (4.2-kg/m^2) kevlar and an outer shell of 8-oz/yd^2 (2.4-kg/m^2) nylon; and a fragmentation protective helmet made of multiple layers of kevlar fabric coated with a resin and compression molded. The helmet was tested in two different versions, one using 38-oz/ft^2 (.11-kg/m^2) kevlar, and one using 30-oz/ft^2 (.09-kg/m^2) kevlar. Soldiers wore the PASGT helmets and vests, and also the standard M1 helmet and standard B nylon vest, while participating in an extensive set of performance tests in the tropic jungles of the Canal Zone. The soldiers' performances while wearing the PASGT helmets and vest were equal to or better than their performances while wearing the standard helmet and vest. In addition, the PASGT helmets and vest were rated as substantially better than the standard helmet and vest on the subjective variables of comfort and soldier-acceptance.

Communication and Information Equipment

Included in this category are those items used to transmit, receive, collect and detect information from other troops, the environment, or other instrumentation. Equipment such as radios,

cryptographic devices, telephone equipment, auditory, seismic and vision devices fall within this category. In the case of voice communication equipment, speech intelligibility tests are conducted during the range testing phases in the various tropic environments (open grasslands and jungle areas). The behavior of radio waves and sound are significantly different in jungle vegetation. Readout and control panels are examined to determine if control configurations allow for easy interpretation and usage, if illumination levels are too high or low (if to be used at night or in vehicles and vans), and if easy access can be gained to components for routine maintenance and parts replacement. Observations are made to determine if instrument operations require special training for troops using the equipment. In testing night vision aids and auditory devices, standardized procedures for operational tests have been developed. Such techniques permit objective data collection on detection capabilities of these devices when used in the tropics, and on comparison with normal, unaided jungle vision and hearing.

Small Arms and Weapons

Major human factors considerations include firing accuracy, maintainability, troop acceptance, and safety and load-carrying characteristics (portability). Human factors data are usually acquired through the use of questionnaires and observations of troops during the operational phases of testing.

In 1974, the Dragon antitank weapon was tested for portability in the jungle using the USATTC Man-pack Portability Course (USATTC Staff, 1974), (see paragraph D, below).

A number of other weapons devices have been tested at USATTC. The following involved human factors engineering problems in design, portability, operability, maintainability, and safety. These are listed below.

XM180 Cratering Device (Rising, et al., 1976)

- Was less portable than UK device.
- Needs three- to four-man breakdown for carrying.
- Tripod rope slipped and tangled.
- Two-piece safety plug generates possible human error by not arming.
- Slope charge positioned backwards.
- Rocket motor clamp too high and too hard to close.
- Possibility stepping on cap.
- Striking the handle could fire system.
- Packing crate too large and heavy, did not meet standards.

XM124 Demolition Firing Device (Emge, 1975)

Instruction booklet complicated and confusing.
Light from continuity check display visible at night to 100 feet; operator must shield with body.
Red knob insulation broke in use; slit for wire was too deep; base was exposed. Redesign necessary to eliminate accidental firing and maintain 100-percent reliability for purposeful firing.

40MM Signal Series Cartridges (Huyck, 1974)

No specified system for carrying in jungle.
Perceptual-psychophysiological problem with green parachute flare--appeared as white yellow. Recommended shift of green parachute flare toward a truer green (520 nanometers).

XM47 E3 Grenade (Skittering) (Ellenberger, 1974)

Preferred smaller size grenade; respondents had normal size hands (5 to 95 percentile).
Difficulty in pulling safety pin; instrumented pull force was within criterion values.
Wet hands caused difficulty in moving safety latch.

Miscellaneous Equipment

These items include those that cannot be categorized as a family of materiel, or those for which human factors engineering applications play a very minor role in tropic testing. Such items include foodstuffs, large storage vessels, containers, ammunition, mines, chemicals and internal components being tested as part of a larger item not being tested (e.g., a truck engine installed in a standard Army vehicle). As a rule of thumb, Human Factors evaluations may be required when the equipment to be tested has a large number of controls, or involves a large number of manipulations in order to be set up, operated or taken down; when special training is required for operation ; when equipment is portable and must be hand-carried by troops; if the equipment is unique or novel; whenever a tropic test only will be conducted; if complex supplemental equipment must be used along with the main test item; when traditional MOS skills will be made obsolete by its adoption.

The following three items were tested at USATTC. Human factors problems and recommendations are listed for each item. Tropic related effects are indicated by a plus (+).

Air Supported Roof (Coen, 1975)

Inadequate procedures for anchor emplacement.
\+ Water in pit made it impossible to pull sections by standing in pit; lacked procedure for pulling roof section with rope from top of berm.

Poor diagram and explanation of roof connectors; hard to twist.
Maintenance manuals incomplete
+ Temperature/humidity air velocity tolerable only to one-half hour in daytime and at night.

XM4 Document Destroyer (Novack, 1975)
Procedure for lighting starter mix was unreliable.
Lacked instructions on outside.

AN/PAS-7 Hand-Held Thermal Viewer (Chura, et al., 1976)
Exceeded weight criterion for holding at eye level for extended periods of time; needs tripod or similar support.
Thumb-operated range focus lever was not within normal thumb reach; lever should be lengthened.
Focus dial was more than 25 times harder to turn than the Human Factors Engineering criterion.

D. PORTABILITY IN THE JUNGLE

General

Men as well as materiel may fall short of predicted performance when operating in harsh combinations of tropic environmental conditions. The first US Marines in South Vietnam were assigned to a valley south of Da Nang. They were rugged and ready to fight; but in their first helicopter-borne mission, 35 to 100 men suffered heat prostration and had to be hospitalized.

A 1973 report by the US Army Natick Development Center (Kennedy, et al., 1973) presented an overview on the subject of load-carrying. According to the study, there are four considerations: the capacity of the load-carrying equipment, the weight of the load, the carrying of man-portable equipment assigned to technical units, and the best method of distribution and carrying. The study traces the various load carrying equipment from World War II through Vietnam and carries through the LINCLOE (Lightweight INdividual CLOthing and Equipment) system. It then analyzes the infantryman load in detail, listing the various weights of individual items of clothing and equipment. It summarizes the list with this statement: "It is evident that we are dealing with very heavy loads for any soldier to carry. Despite the continually increasing awareness of the impact of heavy loads on the soldier's mobility in any climate, and his susceptibility to heat exhaustion collapse in jungle or desert operations, current loads have reached very high levels." Work rate and energy cost are discussed and a formula for predicting the work demand is presented. The report states that in a hot environment, the extra heat production demanded by the extra work-load, compounds the risk of heat exhaustion collapse. The problems of heavy loads tend to be overlooked because

most of the load carriage studies are conducted in comfortable environments. Thus, the physiological impact of a heavy load is underestimated when the soldier is committed to combat in extreme environments. In jungle environments excessive sweat frequenty cannot be evaporated. The soldier derives no benefit from sweating; and the risk of heat exhaustion collapse, already increased by the extra heat production, is further augmented by dehydration of the body. Furthermore the sweat drips into his eyes and soaks his skin to make it more vulnerable to abrasion. Increased incidence of skin infections and foot blisters are common under such conditions.

Effects of Weight and Length on Performance

The Human Engineering Laboratory carried out a study in 1972 (Torre, 1973) which utilized a portability course to investigate the effects of weight and length of simulated antitank weapons on the performance of infantrymen who would have to carry any new antitank weapons that might be developed. In addition to objective measures of performance on the portability course, subjective evaluations were obtained of the difficulty the soldiers experienced in carrying the simulated antitank weapons. Briefly, the results of this study indicated that whenever the simulated antitank weapons were heavier than 8 pounds (in addition to approximately 36 pounds (16 kilograms) of clothing and regular equipment), or were longer than 31 inches (78 centimeters), the soldiers' performances were adversely affected and they showed more reluctance to carry the weapons based on subjective measures.

Effects of Heat Stress on Performance

The Human Engineering Laboratory provided a review and critique of methodology used in measuring the effects of heat stress on performance (Jones, 1970). Research until 1970 reflected a wide divergence of opinions regarding the magnitude, direction, and significance of performance changes occurring under conditions of high temperature, humidity and solar radiation. An attempt to resolve major conflicts in experimental findings led to a detailed examination of such factors as thermal stress indices, exposure times, and acclimatization. The role of the subject in thermal stress research was discussed, with emphasis on the contribution of such psychological variables as personality and motivation to performance change. The report stated: "Taken as a whole, the literature reviewed provided no clear-cut criteria upon which to base predictions of mental or psychomotor performance under thermal stress conditions. The basic lack of agreement between the various studies is primarily the result of a generalized failure to standardize experimental conditions" (emphasis added).

Human Factors Aspects of Infantry Operations

A study conducted by the US Army Natick Development Center (Tambe, Stembridge, 1966) provides a descriptive sample of some of the important elements of the human factors aspects of infantry operations in the jungle. The study explores human factors problems associated with jungle operations by means of field observations made during tactical exercises at the Jungle Warfare Training Center in the Canal Zone. The first exercise was a company patrol base operation performed by reconnaissance and combat patrols, and the second exercise was a raid. Activity data, meteorological data, geographic data, and data on the incompatibility of equipment items were collected by observers accompanying the rifle squads. The study was concerned primarily with describing jungle combat situations and determining activities and tasks required by the man-equipment system. Quantification was limited to major categories of reconnaissance patrol, combat patrol and raid; sub-activities were recorded secondarily as having occurred during major activities. Mobility rates were influenced by load, tactics, motivation, size of the unit, trafficability, physical condition of troops, time allotted to accomplish the mission, decisions of commanders, temperature, terrain and vegetation. Effective temperatures were calculated to indicate heat stress. It was concluded that when common activities exist between soldiers in a jungle and soldiers in other environments, the main differences in performance are the requirement for more time in the accomplishment of some tasks and in the adaptation of techniques. The major human factors problems arose from requirements for increase in mobility, relief from effects of heat, reduction of combat loads, and acceptance of rations. Data were taken during both dry and wet season on the major activities of the combat patrol, reconnaissance patrol and raid patrol (Williamson and Kindick, 1974). The mobility rate of all patrols showed significant differences between the dry and wet seasons, but such a rate change could not be explained entirely by the environmental conditions. The slower mobility rate of all patrols during the wet season could, in part, be attributed to (a) the prevalence of mud, (b) high humidity and temperatures, (c) low visibility, and (d) greater proliferation of vegetation. The frequency of obstacles (streams, gullies and deadfalls) were significant factors in ease of mobility in both seasons.

USATTC Portability Studies

To develop data and test procedures for human performance in the humid tropics, and suitability of test items designed for use by soldiers in the jungle, USATTC conducted portability investigations in the Panama Canal Zone beginning in 1972.

A standard 4-kilometer course (referred to as the Man-Pack Portability Course) was established in jungle terrain and vegetation

to yield group and individual scores on timed performance events and physiological factors. A study compared seasonal foot mobility by testing soldiers in the dry and wet seasons. A total of 100 soldiers traversed the course carrying a standard 25-pound (11 kilograms) load. Measurements were made of a forced march, an uphill run, double timing, normal walking, total course time, weight loss, and water consumption. A Test Operations Procedure on man-pack portability testing in the tropics was prepared as a result of this study.*

A typical combat patrol in jungle areas, determined from literature reviews and interviews with Vietnam veterans, averaged about 4 kilometers--one day or less in duration. Main objectives were search, clear, observation or reconnaissance; equipment carried typically included pistol belt, small pack, canteens, tools for clearing areas or setting up bases, individual or crew-served weapons, ammunition and radios; main difficulties encountered while on jungle patrol were overly heavy or improperly secured loads, discomfort and irritation caused by straps, awkward equipment configurations, and entanglement of equipment in heavy underbrush and vines. Patrol activities included walking at slow, normal, and fast paces, double timing or running for short distances; typical load was about 25 pounds (11 kilograms) depending upon equipment required for a given mission.

The interviews and literature survey resulted in the following guidelines for selecting objective test course events with a minimum sacrifice of realism: test in a natural environment as similar as possible to use conditions; choose site or course that includes terrain and vegetation representative of use areas; select test subjects who represent the user population; perform operations closely related to tactical situations; consider unexpected variables in the natural environment (animals, insects, fear) as valid factors influencing behavior that should not be controlled; when possible, use objective measures (interval scales such as time, distance, weight) that provide reliable data with minimum interference to the conduct of tests; use expertly devised subjective measures when the level of technology does not permit objectivity.

Results and conclusions were as follows:

Time performance events may be classified in a two-way classification scheme: (a) Short time (under 2 minutes) versus long time (1/2 hour or more), and (b) soliciting extra effort (some continued exertion beyond a normal pace) versus no extra effort solicited (typical or normal performance). Reliable data may be obtained from the following three cells: (a) Short time/extra effort, such as the uphill run and double time, (b) long time/extra effort, such as forced march, and (c) long time/no extra effort,

*TECOM Test Operations Procedure 1-3-350, Man-Pack Portability Testing in the Tropics, (USATTC), January 1973.

such as normal walk. Data from short time/no extra effort events, such as the low crawl, proved to be unreliable. Short time/extra effort events and long time/no extra effort events were independent estimates of performance levels. This was true when the short time event demanded near maximum effort and the long time event was measured in an unobtrusive manner.

The physical facility and course events provided safe, standardized procedures for portability tests of items weighing up to 25 pounds (11 kilograms) that must be man-packed through the jungle. For tests of items weighing over 25 pounds (11 kilograms), unscheduled rest breaks were instituted when indicated by physiological monitoring and recording instrumentation.

Significantly longer performance times were obtained in the wet season on the total 4000-meter MPPC time, 1585-meter forced march time, 2263-meter normal walk time, and 91-meter uphill run time. The ratio of wet season to dry season time was about 1.2 to 1.0. The increased amount of rainfall and resultant increase in percent soil moisture (from 26.3 percent in dry season to 63.3 percent in wet season) were the main reasons for seasonal performance differences. Heavy rainfall enlarged and deepened waterways. More soil moisture caused loss of foot traction, slowing progress through the jungle at all points.

Consistent differences in seasonal MPPC performance are often manifested in materiel testing. Many tropic tests should be conducted so that seasonal effects can be documented. Data from previous tests of similar items are not usually appropriate for predicting the effects of one season from the other; however, the data on performance times from this investigation indicated that a multiplier of 1.2 can be used with confidence to convert dry season man-pack data to wet season performance data.

The double time event did not produce significantly different seasonal data. The double time event was too short (61 meters) and too easy, occurring over relatively unencumbered, flat terrain, to yield seasonal differences. The higher soil moisture content did not produce traction problems on the flat terrain. In an analysis of variance of season (2) x subject age (3 levels) x subject weight (2 levels), there were no significant main effects or interactions. There was a one-to-one correspondence between seasons.

No significant seasonal effects were found for physiological indicators of absolute body weight loss, absolute amount of water consumed, absolute amount of sweat lost, and percent of body weight lost as sweat. A 2 (age level) x 2 (weight level) analysis of variance of sweat loss produced no significant differences among age or weight groups. In both seasons, subjects lost 1 percent of their body weight per hour while traversing the course.

Because the age and weight groups were restricted in range and in numbers of subjects, the similarity of performance among groups should not be generalized.

Jungle march rates were slower than soldiers' usual march rates. The march rate for the uphill run, a 100-yard (91-meter) dash up a steep slope through mud and vines, was 19.7 minutes-per-mile (10.6 minutes-per-kilometer); the double time rate, over flat, less tangled terrain, was 12.6 minutes-per-mile (6.8 minutes-per-kilometer). The fast paced, long distance forced march was performed at a rate of 27.5 minutes-per-mile (14.8 minutes-per-kilometer), while the normal walk rate was slower at 35.6 minutes-per-mile (19.2 minutes-per-kilometer). All march rates were recorded under standard equipment load of 25 pounds (11 kilograms) which included clothing and M-16 rifle.

Physiological indicators, performance times and subjective measures each constituted relatively independent domains within the performance envelope, and all were necessary for a complete evaluation of man-materiel systems in the tropics.

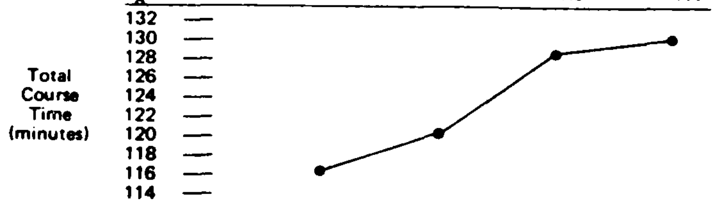
The validity of the last conclusion was demonstrated in the test of the Dragon antitank weapon in the Canal Zone (USATTC Staff, 1974). Jungle portability tests using the preceding methods showed no significant differences between the Dragon and the 90mm recoilless rifle. Subjective evaluations of portability based on controlled comparison tests showed that the 90mm was considered a heavier load. When carried high on the shoulder, it caused sore shoulder muscles and required constant adjustment with both hands and arms. The 90mm snagged on vines and underbrush, forcing the carrier to bend and often lose balance, and generally created more personal discomfort than the Dragon. When an accelerated march rate was required in the jungle, the superior portability aspects of the Dragon were more apparent, and resulted in greater ease and comfort of carriage. Suggestions for modifications of the Dragon to facilitate carrying through the jungle were: (a) add padding to the steel component which strikes the back when the bearer travels downhill or jumps, (b) install a sliding 6-inch (15-centimeter) pad on the sling for cushioning on the body (back or shoulder), (c) add a leg strap on the sight bag to prevent "flapping" when the bearer is running, (d) lower the clamps on the sight bag to put the weight on the bearer's hips for less strain and easier control, and (e) add a protective coating to the end caps to lessen damage and prevent snagging.

A Pilot Study on Load Carrying Test Methodology (Williamson and Kindick, 1975) was conducted by USATTC in the Canal Zone to determine sample sizes needed in future tests requiring a jungle patrol, and to determine the utility of two human performance decrement measurements. Combat troops carried loads from 25 to 55 pounds (11 to 25 kilograms) over the 4-kilometer MPPC. In general, time to perform activities tended to increase with increased load (table XI-3). Body

weight loss from sweating was about the same for all load-carrying troops regardless of load, but load-carrying troops lost significantly

Table XI-3. Summary Data for Total Course Time

Statistic	Active Groups (pounds (kilograms) carried)			
	25 (11)	35 (16)	45 (20)	55 (25)
N (groups)	2	2	2	2
X (minutes)	117.0	120.5	129.5	131.5
$\sigma_{\bar{X}}$	2.1	7.4	1.8	7.4



more weight than a control group that had rested. Sample size of 12 groups of three individuals, or 16 groups of two individuals, were determined sufficient for future normative data collection studies within the 25- to 55-oound (11 to 25 kilograms) load range.

USATTC Performance Decrement Considerations

Two methods were established for measuring performance decrement for use in conjunction with the jungle portability test course discussed previously. In addition, a workable physiological safety monitoring system was devised for tests where heat stress might be a factor. These three performance measurement systems are discussed below.

Laser Rifle Fire Simulator. The Lightweight Eyesafe Gallium Arsenide Laser rifle was adapted for use as a testing device by USATTC (Williamson, et al., 1976). Developed by the US Army Training Device Agency at the Naval Training Equipment Center, Orlando, Florida, the Laser Rifle Fire Simulator is used to measure tropic effects on human performance.

A quick-fire laser rifle jungle test area (figure XI-3) is located near the beginning and end of the MPPC, so that persons may be tested immediately before and after they traverse the MPPC. The laser rifle system consists of an eye-safe laser transmitter attached to a plastic model of an M16A1 rifle, and six standard pop-up silhouette targets to which photo-diode laser receivers have been attached (figure XI-4). The silhouette targets are programmed to pop up in random order, one at a time, and remain up for 3 to 4 seconds before automatically being lowered. If the soldier detects the target, aims and hits it within this time, the target is lowered immediately and a hit is scored. A test-series of 72 targets is programmed so that a new target appears every 5 seconds. The test-retest reliability of the system was measured at r_{xx} = .91, based on 28 soldiers who rested for 2 hours between tests (approximate time to traverse portability course).

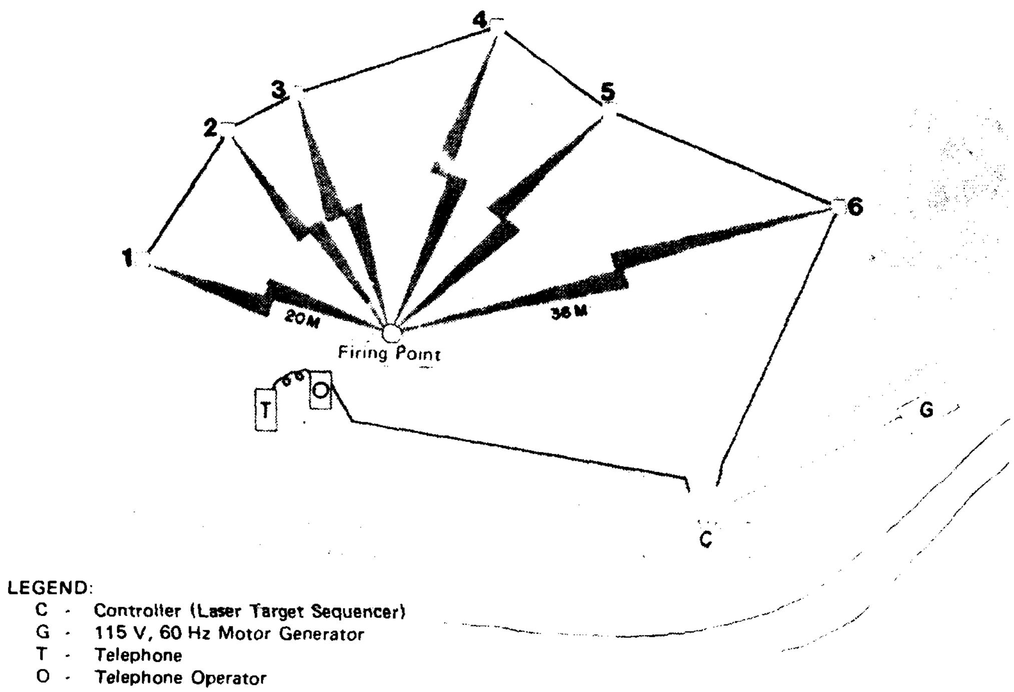


Figure XI-3. Quick-Fire Laser Rifle Jungle Test Site

The range of scores on the pre- and post-tests was from 2 to 68, out of a possible 0 to 72. Target difficulty (proportion of target presentations hit) ranged from .51 to .82 for the six targets. The mean intercorrelation among separate target scores was r = .61.

Jungle Land Navigation. The land navigation test measures the ability of the soldier to find his way through the jungle and to estimate how far he has traveled. The land navigation test site is located near the entrance to the human factors jungle test area, where it is used as a performance measure before and after an individual is tested on the portability course. Using a lensatic compass, a soldier employs land navigation or "orienting" techniques to find his way through dense jungle, completing a series of problems within a 160-foot (48-meter) diameter circle in less than half an hour. On each problem, the soldier "shoots" a given azimuth, walks in that line (re-shooting as necessary depending upon the distance at which a clear reference point is visible--usually about 40 feet (12 meters)), keeps track of the distance he has walked (pacing), arrives at a stake in the ground, and records the stake number and his estimate of distance from his origin point. His destination (right or wrong since there are "decoy" stakes close to the correct stake) becomes the origin point for the next problem. A scoring system has been devised so that an error on one problem does not affect a subject's score on any subsequent problem; no monitoring by a test official is necessary except for measuring total time required for a subject to complete all problems of the

Figure XI-4. Performance Test Using Laser Rifle Fire Simulator.

test. Four basic scores result from the test: number of correctly solved problems, amount of error on incorrect problems, accuracy in estimating distance and total time.

Test-retest reliability coefficients (r_{xx}) for these scores (with a 2-hour rest period between test and retest in lieu of traversing the MPPC) were:

	r_{xx}
Number of correctly solved problems	.34
Amount of error on incorrect problems	.33
Accuracy in estimating distance	.83
Total time	.69

These coefficients show that the scores on accuracy in estimating distance, and total time are reproducible enough to be useful measures.

Physiological Safety Monitoring. Soldiers who participate in strenuous tropic tests can be monitored for safety purposes by a biolink telemetry system that was modified to meet tropic field requirements (Williamson and Kindick, 1975). The system monitors heart rate by using a mobile transmitter with a high quality commercial FM receiver-cassette tape recorder as the receiving device. The receiving system is 75 percent effective (100% - 5% electrode adhesion failures - 20% intermittent electrode shorting from sweating = 75%) and is capable of monitoring the heart rate of the soldier for 2 1/2 hours. It is carried by a test official who follows the subject through the jungle at a distance of 50 feet (15 meters). Body temperature is measured with an oral thermometer.

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